CS107, Lecture 9
Arrays and Pointers

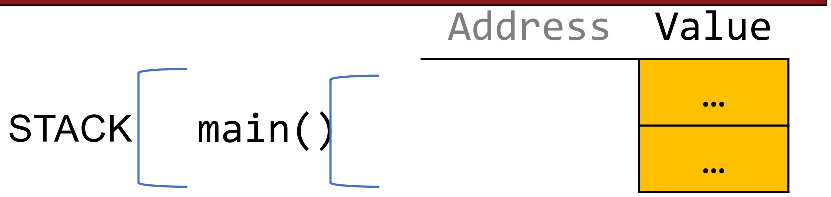
Reading: K&R (5.2-5.5) or Essential C section 6

Ed Discussion

Based on slides created by Cynthia Lee, Chris Gregg, Nick Troccoli, Lisa Yan, Jerry Cain and others.

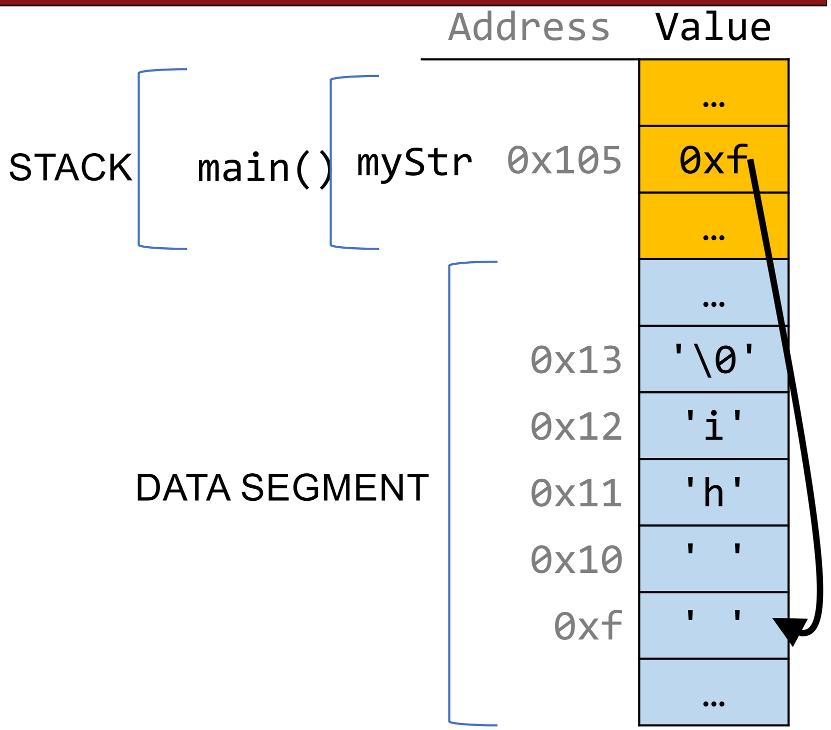
Pointers to Strings

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

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



Pointers to Strings

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

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



Address Value

STACK

main() myStr 0x105 0xf

…

…

…

DATA SEGMENT

0x13 '\0'

0x12 'i'

0x11 'h'

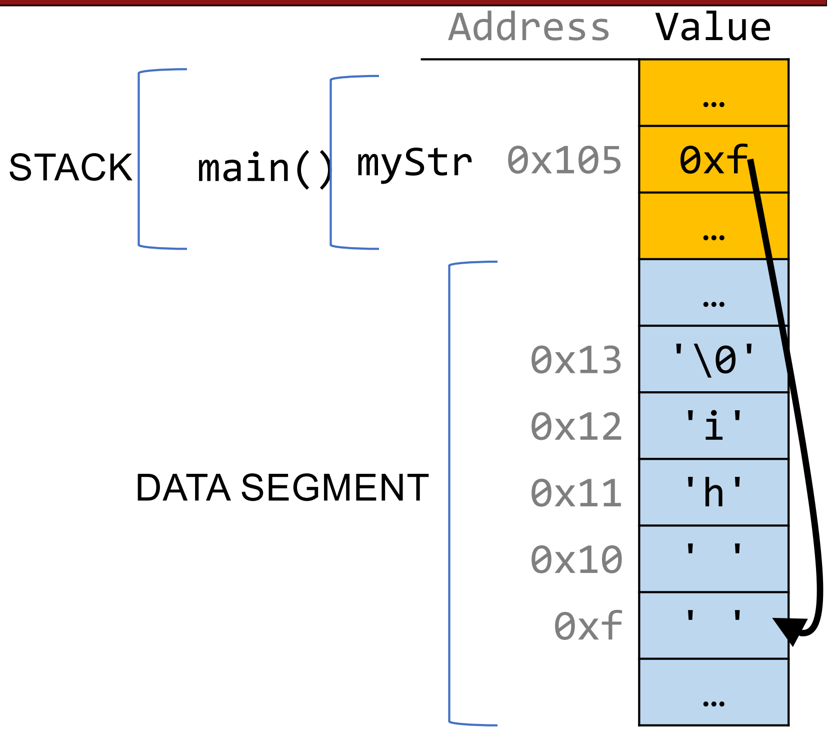
0x10 ' '

0xf ' '

…

Pointers to Strings

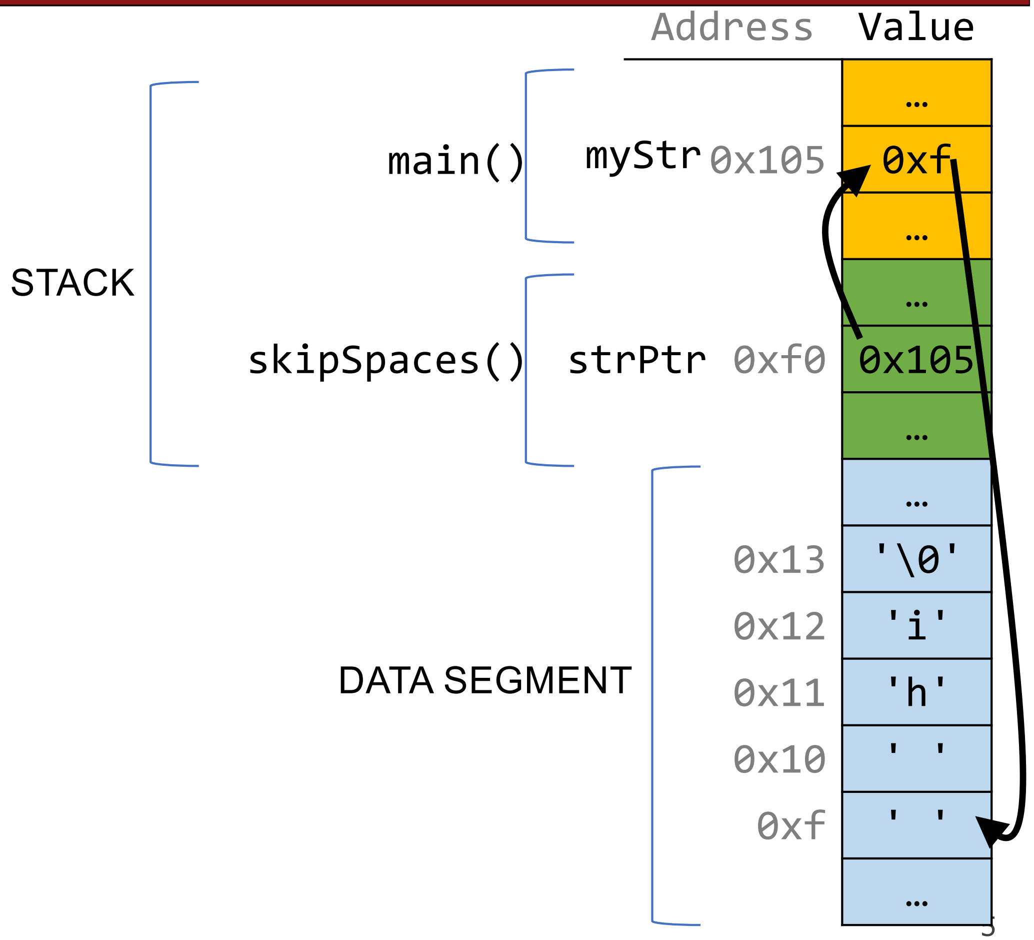
```
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



			Address	Value
STACK	main()			…
		myStr	0x105	0xf
				…
DATA SEGMENT				…
			0x13	'\0'
			0x12	'i'
			0x11	'h'
			0x10	' '
			0xf	' '
				…

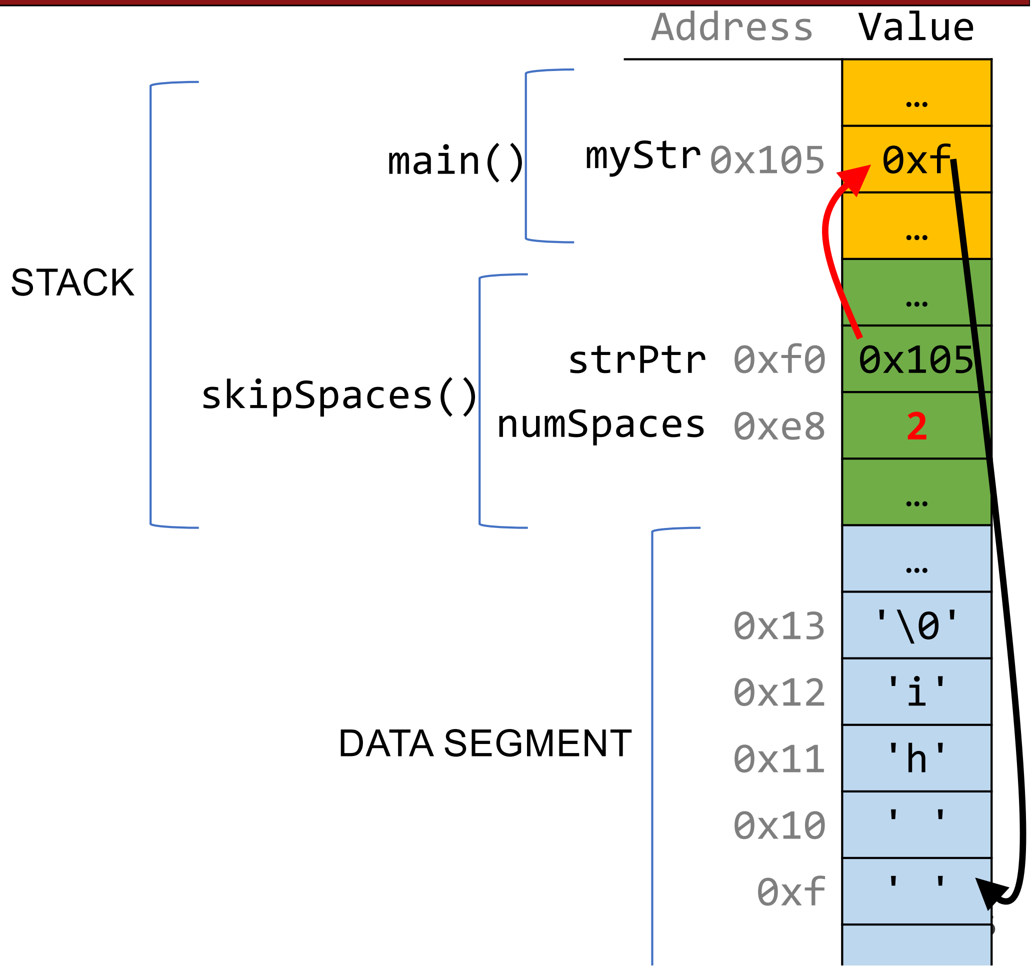
Pointers to Strings

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

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);      // hi
    return 0;
}
```



Pointers to Strings

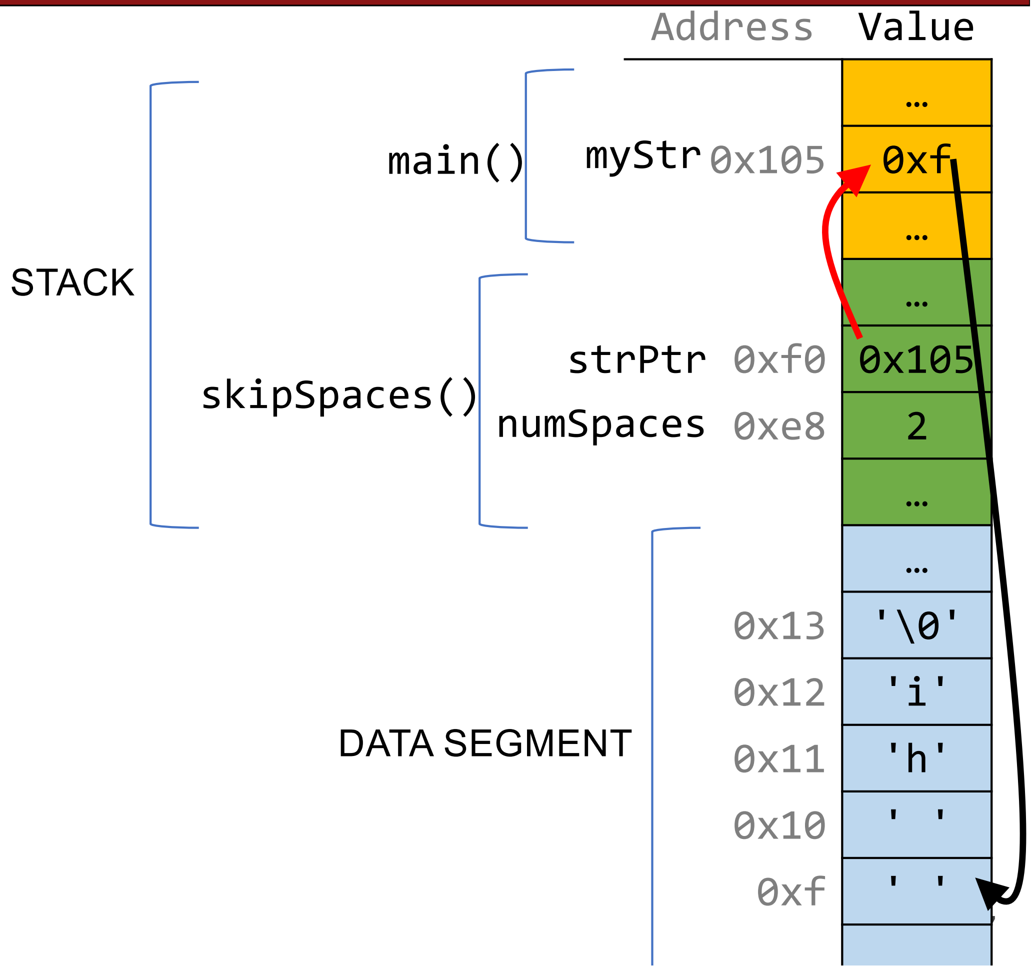
```
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);        // hi
    return 0;
}
```



			Address	Value
STACK				…
	main()	myStr	0x105	0xf
				…
				…
	skipSpaces()	strPtr	0xf0	0x105
		numSpaces	0xe8	2
				…
DATA SEGMENT				…
			0x13	'\0'
			0x12	'i'
			0x11	'h'
			0x10	' '
			0xf	' '

Pointers to Strings

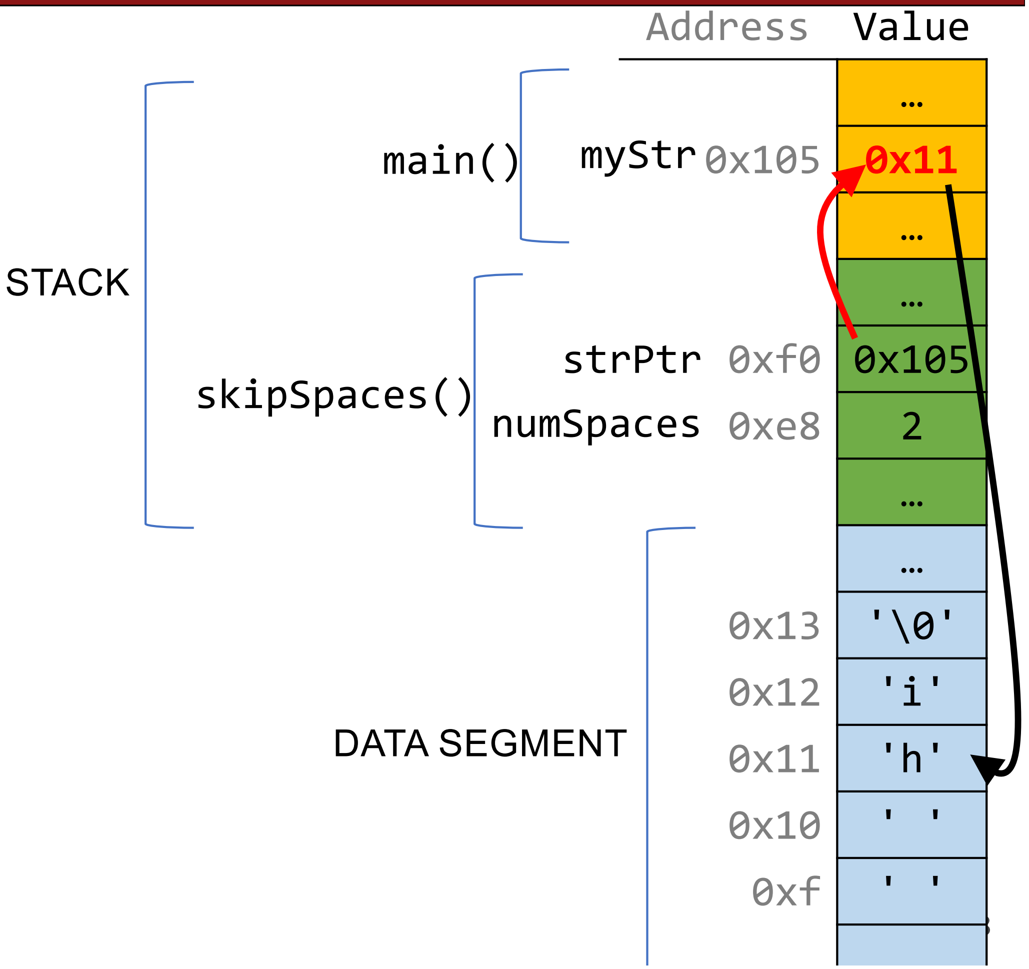
```
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);        // hi
    return 0;
}
```



			Address	Value
STACK	main()			…
		myStr	0x105	0xf
				…
	skipSpaces()			…
		strPtr	0xf0	0x105
		numSpaces	0xe8	2
				…
DATA SEGMENT				…
			0x13	'\0'
			0x12	'i'
			0x11	'h'
			0x10	' '
			0xf	' '

Pointers to Strings

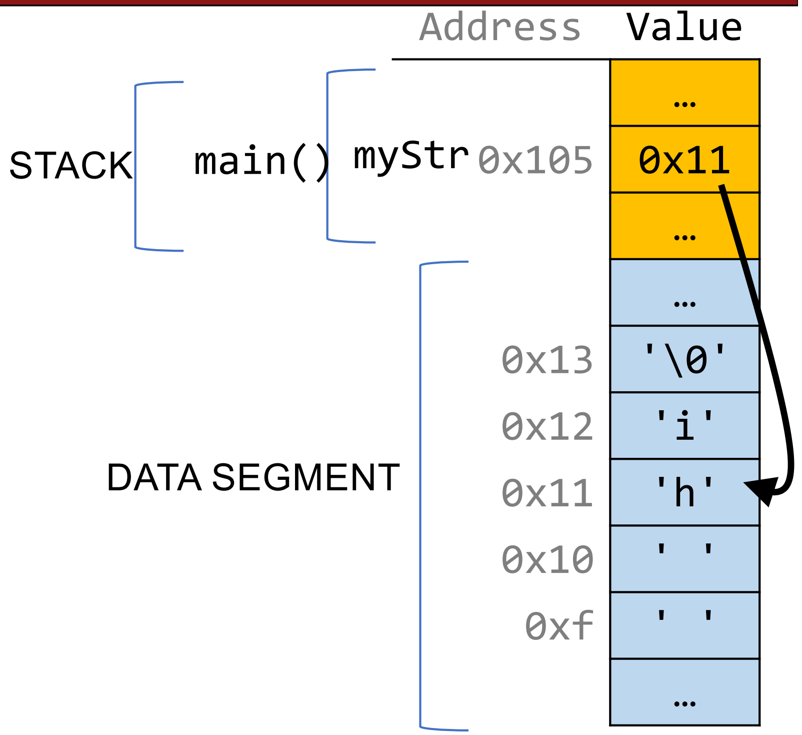
```
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



		Address	Value
main()			…
	myStr	0x105	0x11
			…
skipSpaces()			…
	strPtr	0xf0	0x105
	numSpaces	0xe8	2
			…
			…
		0x13	'\0'
		0x12	'i'
		0x11	'h'
		0x10	' '
		0xf	' '

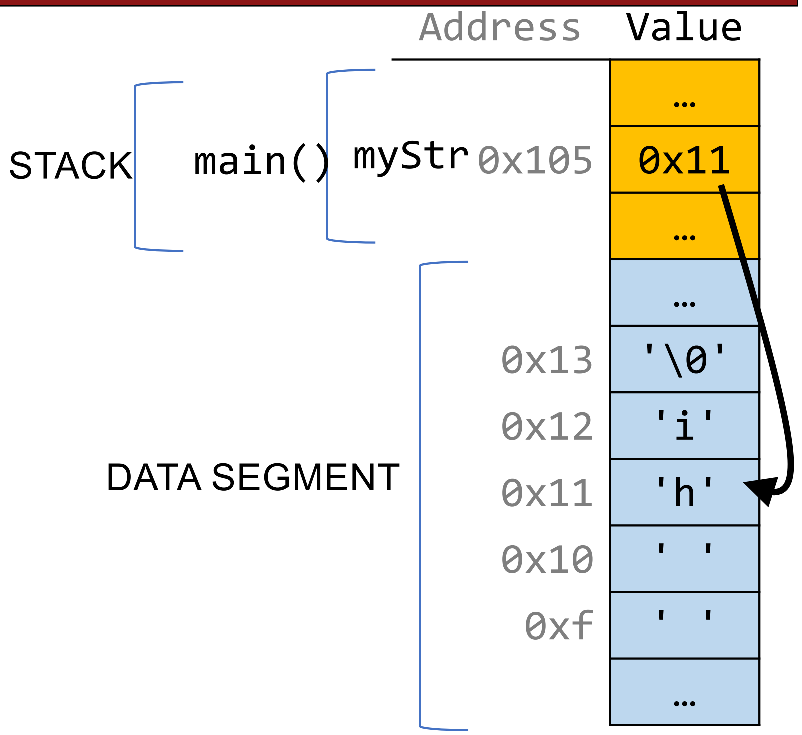
Pointers to Strings

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

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);      // hi
    return 0;
}
```



Pointers to Strings

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

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



			Address	Value
				…
STACK	main()	myStr	0x105	0x11
				…
				…
			0x13	'\0'
			0x12	'i'
DATA SEGMENT			0x11	'h'
			0x10	' '
			0xf	' '
				…

Weird thought – **0x11** *is a string*.

Strings In Memory

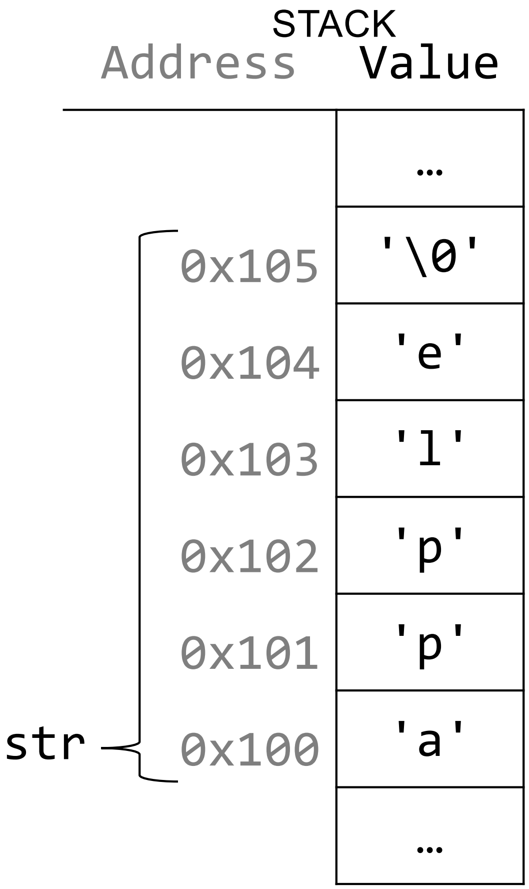
1. If we create a string as a **`char[]`**, we can modify its characters because its memory lives in our stack space.
2. We cannot set a **`char[]`** equal to another value, because it is not a pointer, as it refers to the block of memory reserved for the original array.
3. If we pass a **`char[]`** as a parameter, set something equal to it, or perform arithmetic with it, it's automatically converted to a **`char *`**.
4. If we create a new string with new characters as a **`char *`**, we cannot modify its characters because its memory lives in the data segment.
5. We can set a **`char *`** equal to another value, because it is an assignable pointer.
6. Adding an offset to a C string gives us a substring that's many places past the first character.
7. If we change characters in a string parameter, these changes will persist outside of the function.

String Behavior #1: If we create a string as a `char[]`, we can modify its characters because its memory lives in our stack space.

Character Arrays

When we declare an array of characters, contiguous memory is allocated on the stack to store the contents of the entire array. We can modify what is on the stack.

```
char str[6];
strcpy(str, "apple");
```



STACK

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

String Behavior #2: 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.

Character Arrays

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

```
char str[6];
strcpy(str, "apple");
char str2[8];
strcpy(str2, "apple 2");

str = str2;   // not allowed!
```

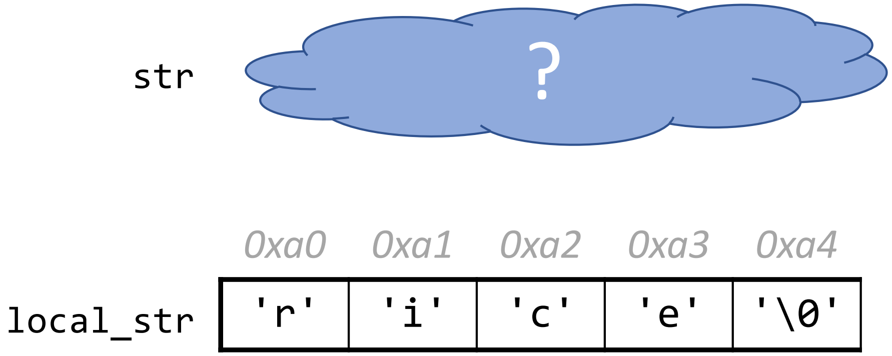
An array's size cannot be changed once we create it; we must create another new array instead.

String Behavior #3: If we pass a **char[]** as a parameter, set something equal to it, or perform arithmetic with it, it’s automatically converted to a **char ***.

String Parameters

How do you think the parameter `str` is being represented?

```
void fun_times(char *str) {
      ...
}

int main(int argc, char *argv[]) {
      char local_str[5];
      strcpy(local_str, "rice");
      fun_times(local_str);
      return 0;
}
```



	0xa0	0xa1	0xa2	0xa3	0xa4
local_str	'r'	'i'	'c'	'e'	'\0'

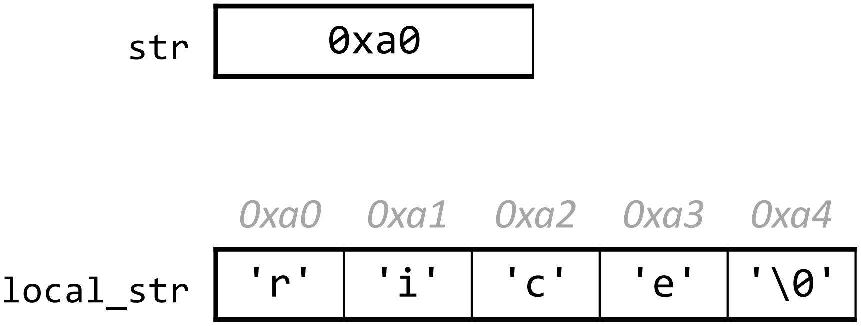
A. A copy of the array `local_str`

B. A pointer containing an address to the first element in `local_str`

String Parameters

How do you think the parameter `str` is being represented?

```
void fun_times(char *str) {
      ...
}

int main(int argc, char *argv[]) {
      char local_str[5];
      strcpy(local_str, "rice");
      fun_times(local_str);
      return 0;
}
```



str `0xa0`

	0xa0	0xa1	0xa2	0xa3	0xa4
local_str	'r'	'i'	'c'	'e'	'\0'

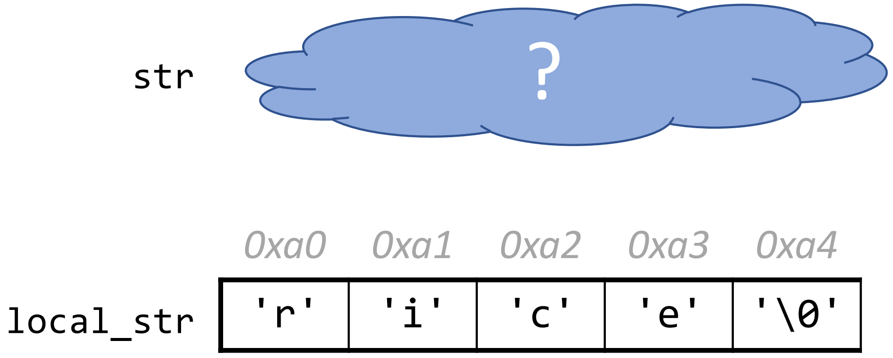
A. A copy of the array `local_str`

[✓ B.] A pointer containing an address to the first element in `local_str`

char * Variables

How do you think the local variable `str` is being represented?

```
int main(int argc, char *argv[]) {
    char local_str[5];
    strcpy(local_str, "rice");
    char *str = local_str;
    ...
    return 0;
}
```



	0xa0	0xa1	0xa2	0xa3	0xa4
local_str	'r'	'i'	'c'	'e'	'\0'

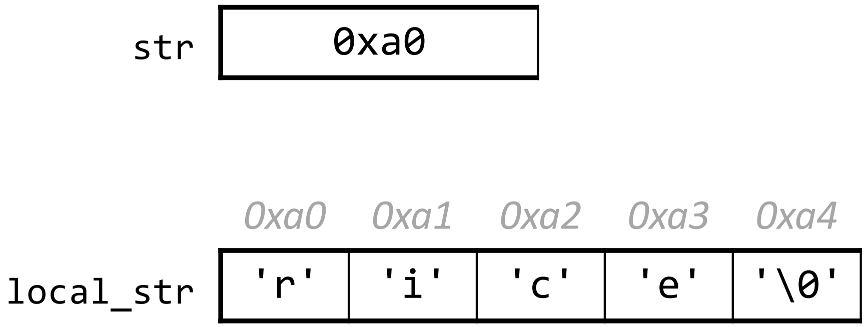
A. A copy of the array `local_str`

B. A pointer containing an address to the first element in `local_str`

char * Variables

How do you think the local variable `str` is being represented?

```
int main(int argc, char *argv[]) {
     char local_str[5];
     strcpy(local_str, "rice");
     char *str = local_str;
     ...
     return 0;
}
```



str 0xa0

	0xa0	0xa1	0xa2	0xa3	0xa4
local_str	'r'	'i'	'c'	'e'	'\0'

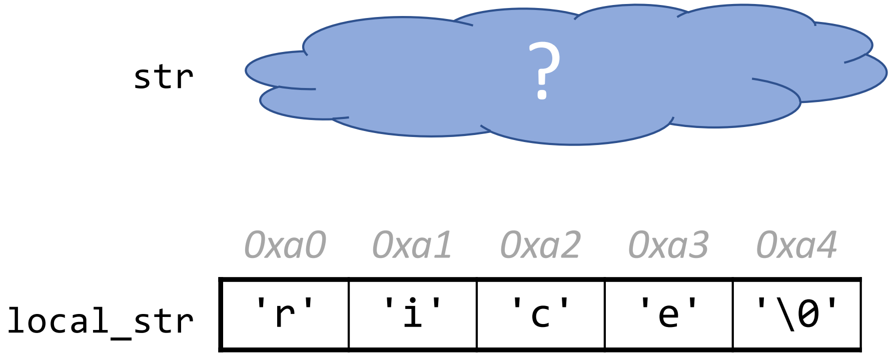
A. A copy of the array `local_str`

[✓ B.] A pointer containing an address to the first element in `local_str`

char * Variables

How do you think the local variable `str` is being represented?

```
int main(int argc, char *argv[]) {
     char local_str[5];
     strcpy(local_str, "rice");
     char *str = local_str + 2;
     ...
     return 0;
}
```



str ?

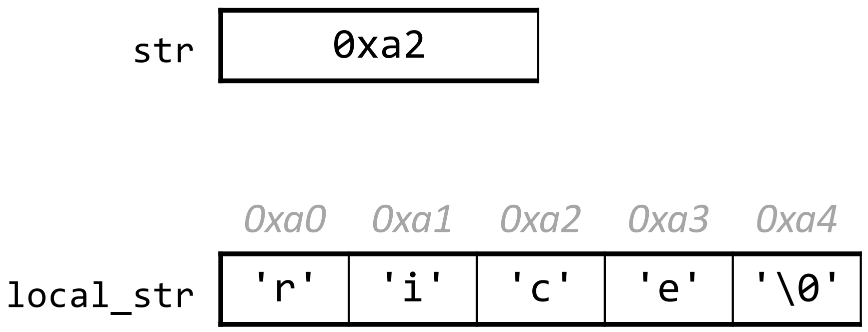
	0xa0	0xa1	0xa2	0xa3	0xa4
local_str	'r'	'i'	'c'	'e'	'\0'

A. A copy of part of the array `local_str`
B. A pointer containing an address to the third element in `local_str`

char * Variables

How do you think the local variable `str` is being represented?

```
int main(int argc, char *argv[]) {
     char local_str[5];
     strcpy(local_str, "rice");
     char *str = local_str + 2;
     ...
     return 0;
}
```



str: 0xa2

	0xa0	0xa1	0xa2	0xa3	0xa4
local_str	'r'	'i'	'c'	'e'	'\0'

A. A copy of part of the array `local_str`

[✓ B.] A pointer containing an address to the third element in `local_str`

String Parameters

All string functions take char * parameters – they accept char[], but they are implicitly converted to char * before being passed.

  - strlen(char *str)
  - strcmp(char *str1, char *str2)
  - …

- char * is still a string in all the core ways a char[] is
  - Access/modify characters using bracket notation
  - Print it out
  - Use string functions
  - But under the hood they are represented differently!
- **Takeaway:** We create strings as char[], pass them around as char *

String Behavior #4: If we create a new string with new characters as a **char ***, we cannot modify its characters because its memory lives in the data segment.

char *

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

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

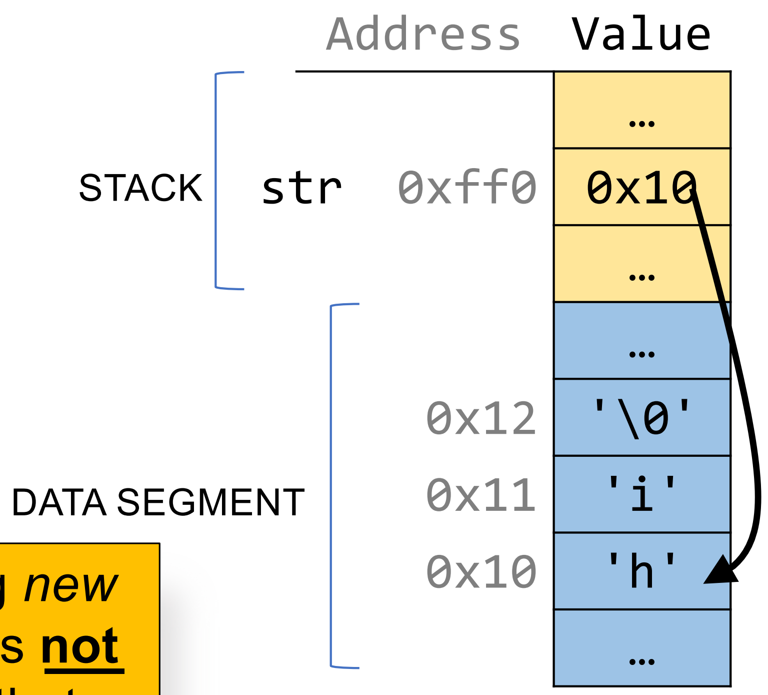
```
~~myString[0] = 'h';~~                // crashes!
printf("%s", myString);           // Hello, world!
```

char *

When we 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”. We *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*.



		Address	Value
STACK			…
	str	0xff0	0x10
			…
DATA SEGMENT			…
		0x12	'\0'
		0x11	'i'
		0x10	'h'
			…

This applies only to creating *new* strings with char *. This does **<u>not</u>** apply for making a char * that points to an existing stack string.

Memory Locations

For each code snippet below, can we modify the characters in **myStr**?

```
char myStr[6];
```

Key Question: where do its characters live? Do they live in memory we own? Or the read-only data segment?

Memory Locations

For each code snippet below, can we modify the characters in **myStr**?

```
char *myStr = "Hi";
```

Key Question: where do its characters live? Do they live in memory we own? Or the read-only data segment?

Memory Locations

For each code snippet below, can we modify the characters in **myStr**?

Key Question: where do its characters live? Do they live in memory we own? Or the read-only data segment?

```
char buf[6];
strcpy(buf, "Hi");
char *myStr = buf;
```

Memory Locations

For each code snippet below, can we modify the characters in **myStr**?

```
char *otherStr = "Hi";
char *myStr = otherStr;
```

Key Question: where do its characters live? Do they live in memory we own? Or the read-only data segment?

Memory Locations

For each code snippet below, can we modify the characters in **myStr**?

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

int main(int argc, char *argv[]) {
     char buf[6];
     strcpy(buf, "Hi");
     myFunc(buf);
     return 0;
}
```

Key Question: where do its characters live? Do they live in memory we own? Or the read-only data segment?

Memory Locations

Q: Is there a way to check in code whether a string’s characters are modifiable?

A: No. This is something you can only tell by looking at the code itself and how the string was created.

Q: So then if I am writing a string function that modifies a string, how can I tell if the string passed in is modifiable?

A: You can’t! This is something you instead state as an assumption in your function documentation. If someone calls your function with a read-only string, it will crash, but that’s not your function’s fault :-)

String Behavior #5: We can set a **`char *`** equal to another value, because it is an assignable pointer.

char *

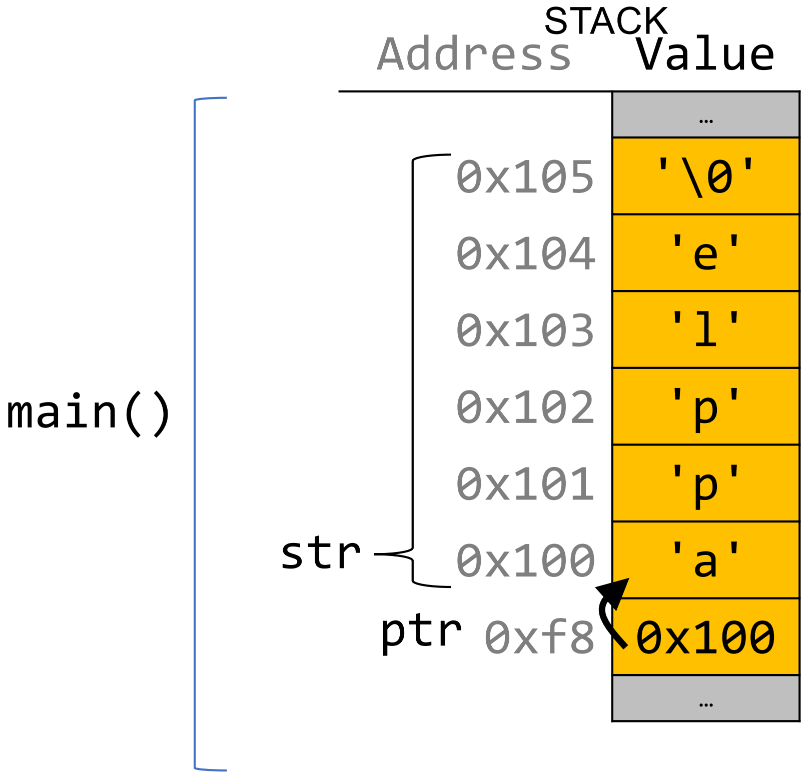
A **char *** variable refers to a single character. We can reassign an existing **char *** pointer to be equal to another **char *** pointer.

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

Arrays and Pointers

We 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];
     strcpy(str, "apple");
     char *ptr = str;
     ...
}
```



STACK

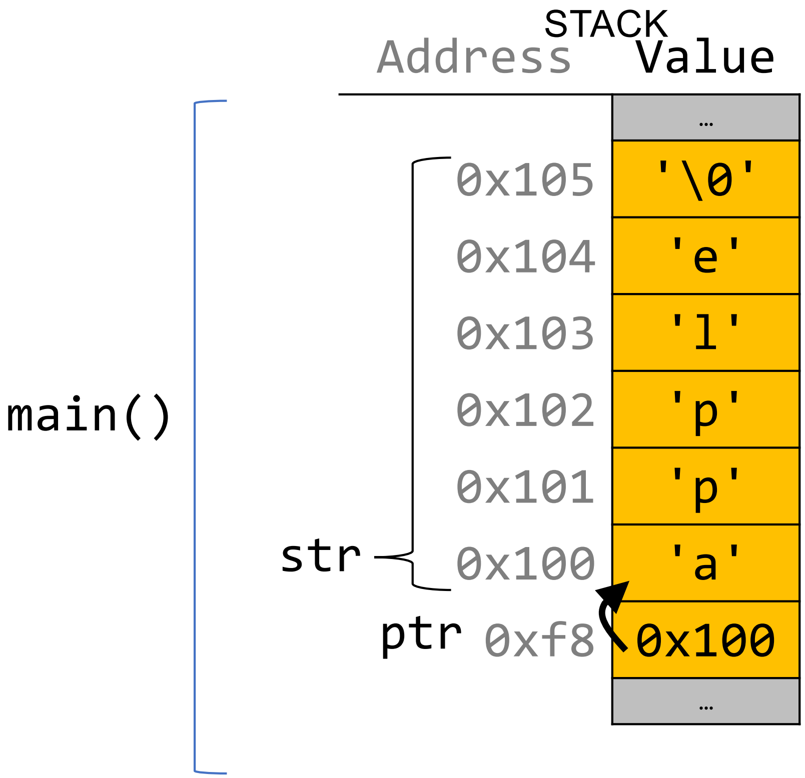
main()

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

Arrays and Pointers

We 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];
     strcpy(str, "apple");
     char *ptr = str;

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

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



STACK

main()

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

String Behavior #6: Adding an offset to a C string gives us a substring that's many places past the first character.

Pointer Arithmetic

When we do pointer arithmetic, we 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'
	…

char *

When we use bracket notation with a pointer, we are 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 fourth1 = str[3];       // 'l'
char fourth2 = *(str + 3);   // 'l'
```

TEXT SEGMENT

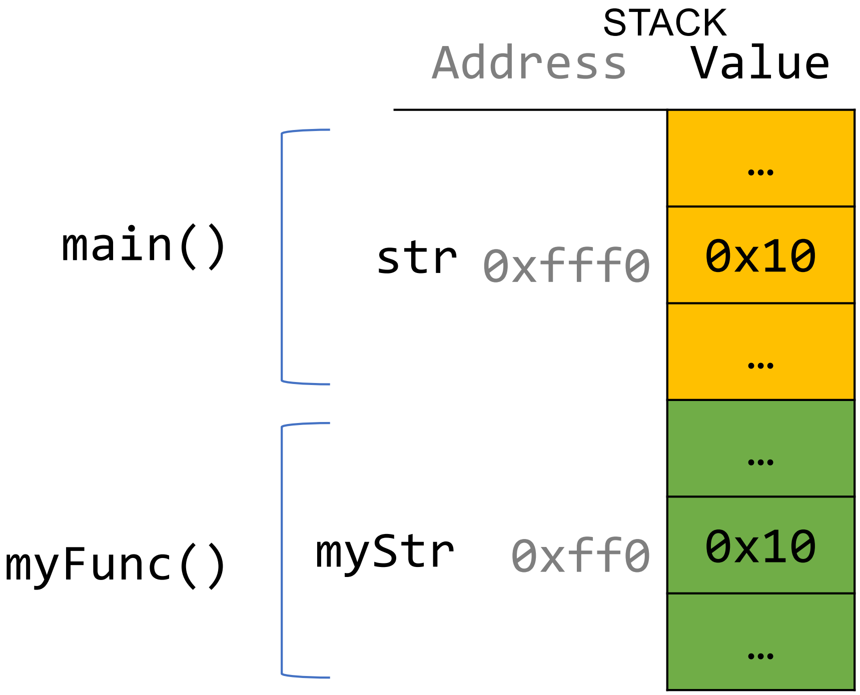
Address	Value
	…
0xff5	'\0'
0xff4	'e'
0xff3	'l'
0xff2	'p'
0xff1	'p'
0xff0	'a'
	…

String Behavior #7: If we change characters in a string parameter, these changes will persist outside of the function.

Strings as Parameters

When we 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.

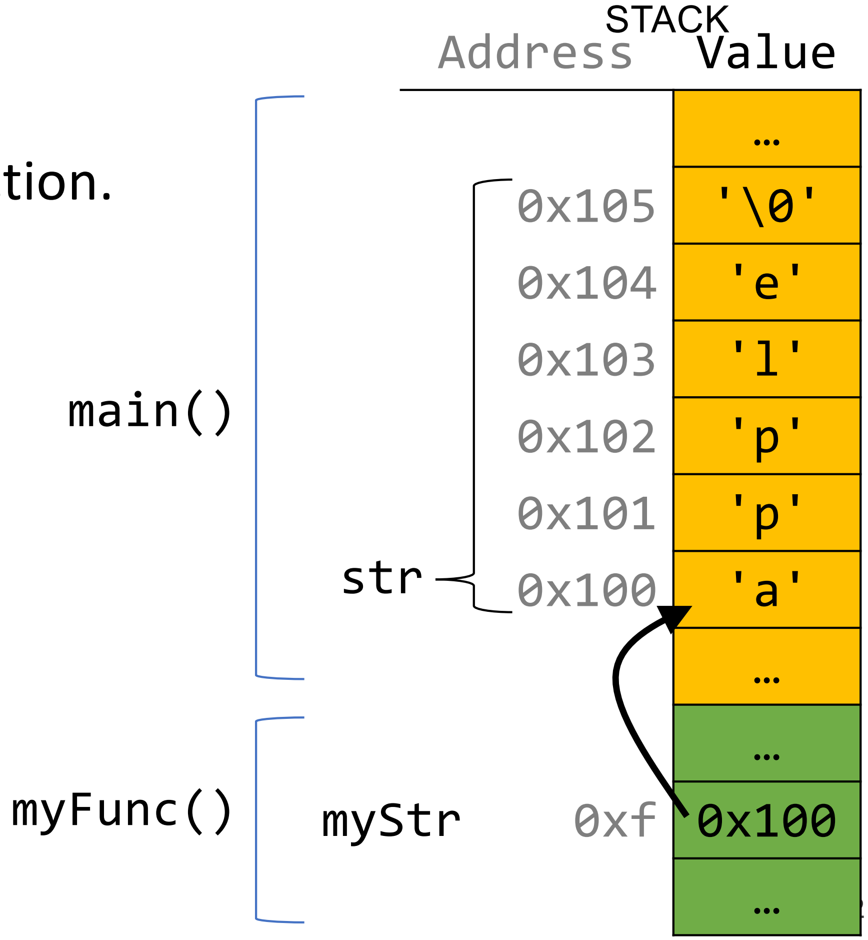
```
void myFunc(char *myStr) {
     ...
}

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



Strings as Parameters

When we 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];
     strcpy(str, "apple");
     myFunc(str);
     ...
}
```



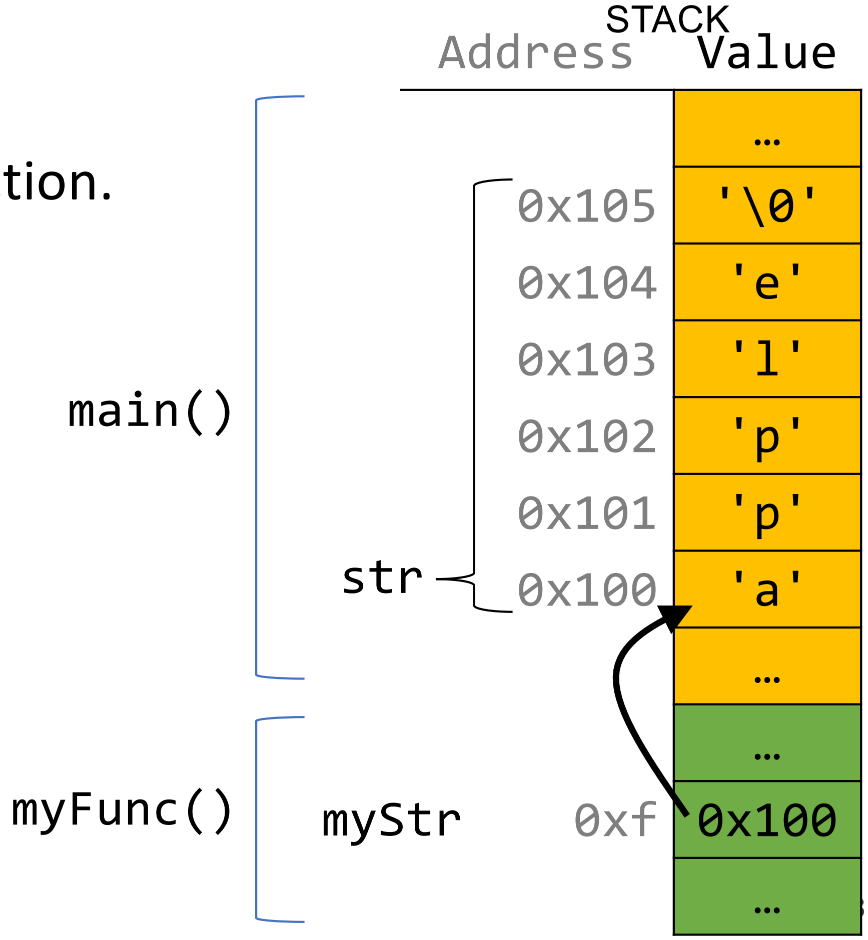
STACK

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

Strings as Parameters

When we 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.

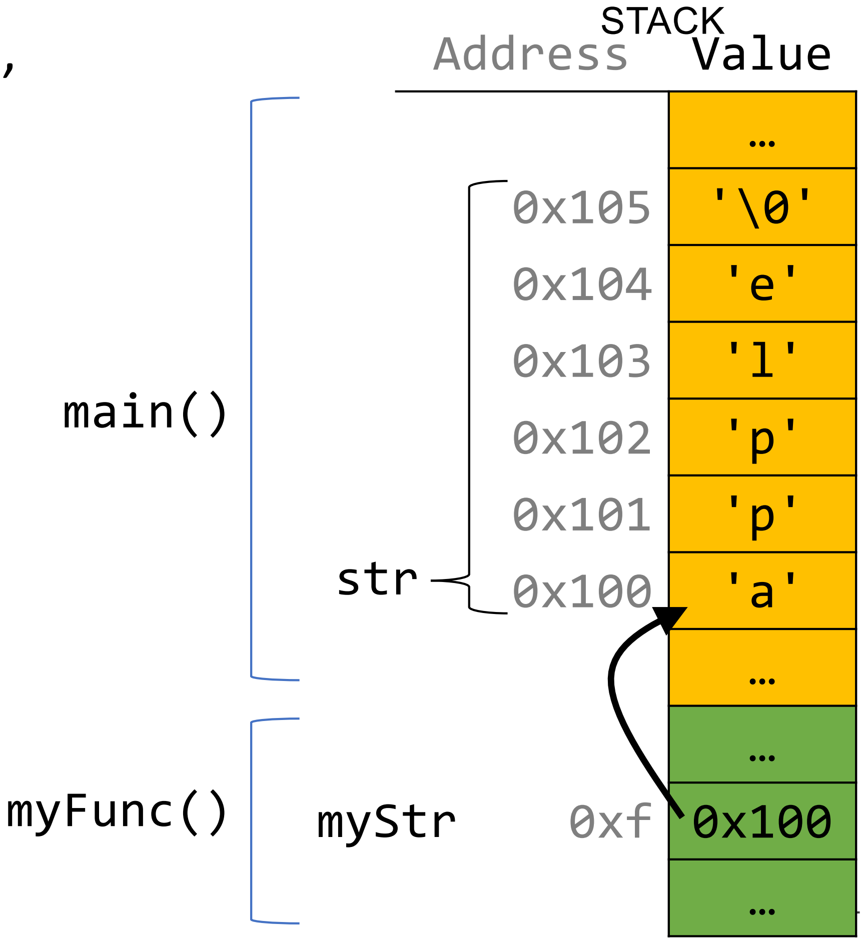
```
void myFunc(char *myStr) {
     ...
}

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



Strings as Parameters

This means if we 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];
     strcpy(str, "apple");
     myFunc(str);
     printf("%s", str);  // apply
     ...
}
```



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 we 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];
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     ...
}
```

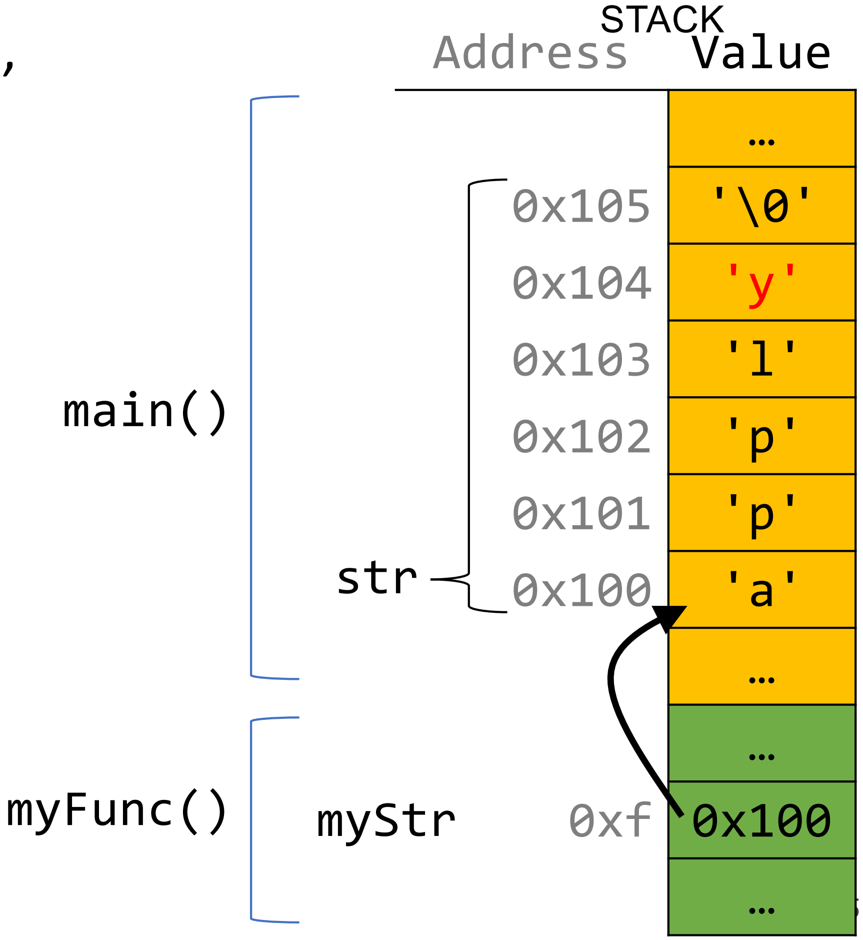

STACK

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

Strings In Memory

1. If we create a string as a **char[]**, we can modify its characters because its memory lives in our stack space.
2. 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.
3. If we pass a **char[]** as a parameter, set something equal to it, or perform arithmetic with it, it's automatically converted to a **char ***.
4. If we create a new string with new characters as a **char ***, we cannot modify its characters because its memory lives in the data segment.
5. We can set a **char *** equal to another value, because it is a reassign-able pointer.
6. Adding an offset to a C string gives us a substring that many places past the first character.
7. If we change characters in a string parameter, these changes will persist outside of the function.

Arrays vs. Pointers

- When you create an array, you are making space for each element in the array.
- When you create a pointer, you are making space for a 64-bit address.
- Arrays "decay to pointers" when passed as parameters.
- &arr does nothing on arrays, but &ptr on pointers gets its address
- sizeof(arr) gets the size of an array in bytes, but sizeof(ptr) is always 8