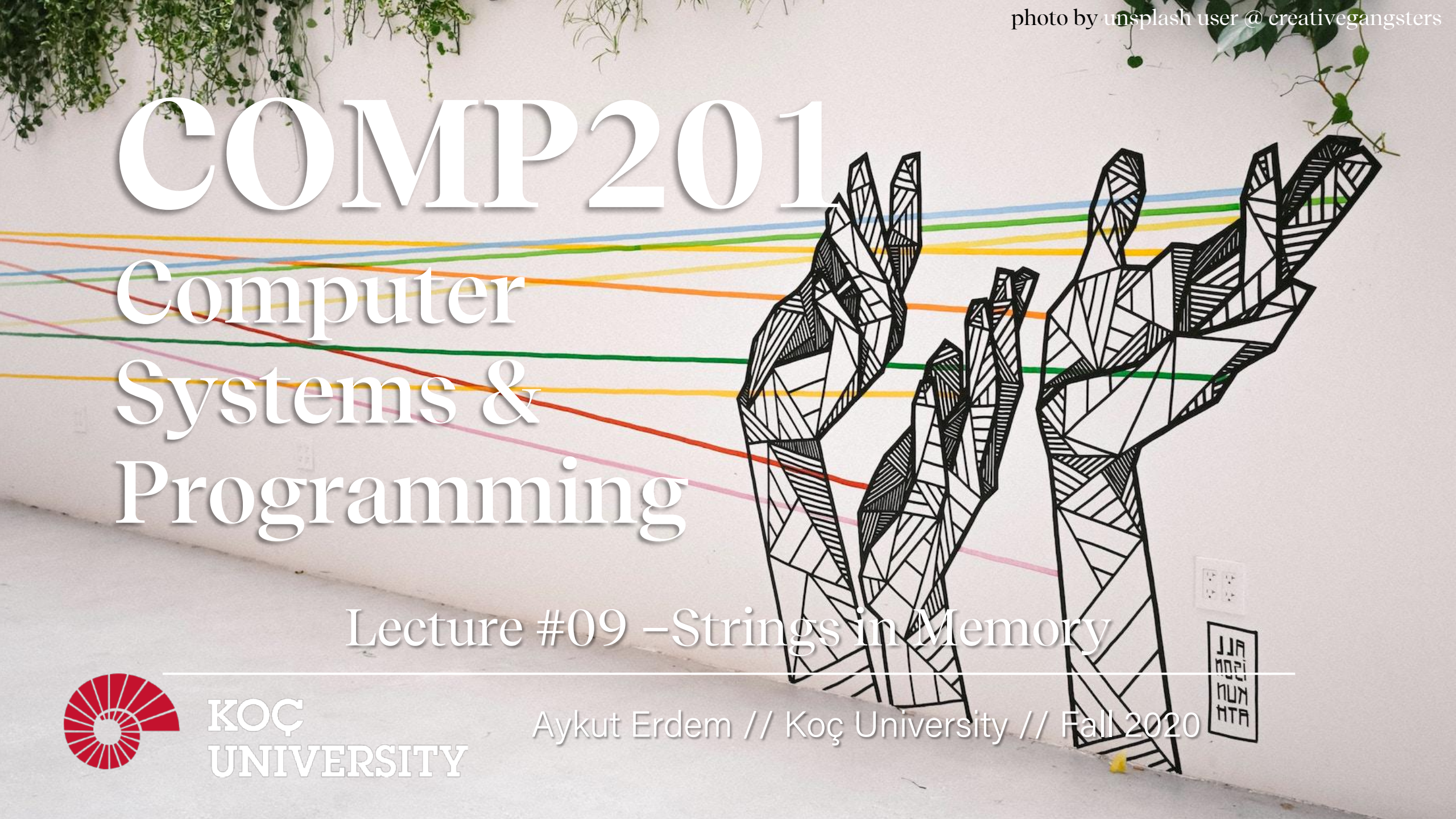


COMP201

Computer Systems & Programming

Lecture #09 –Strings in Memory

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Fall 2020

Good news, everyone!

- You will have more time to work on your lab assignment. The deadlines will be:
  - 22:59:59 for Lab A, B, E, F, and 23:59:59 for Lab C, D.
- TAs will spend more time to review the lab materials and solve some sample problems
- Also see the rules for lab attendance

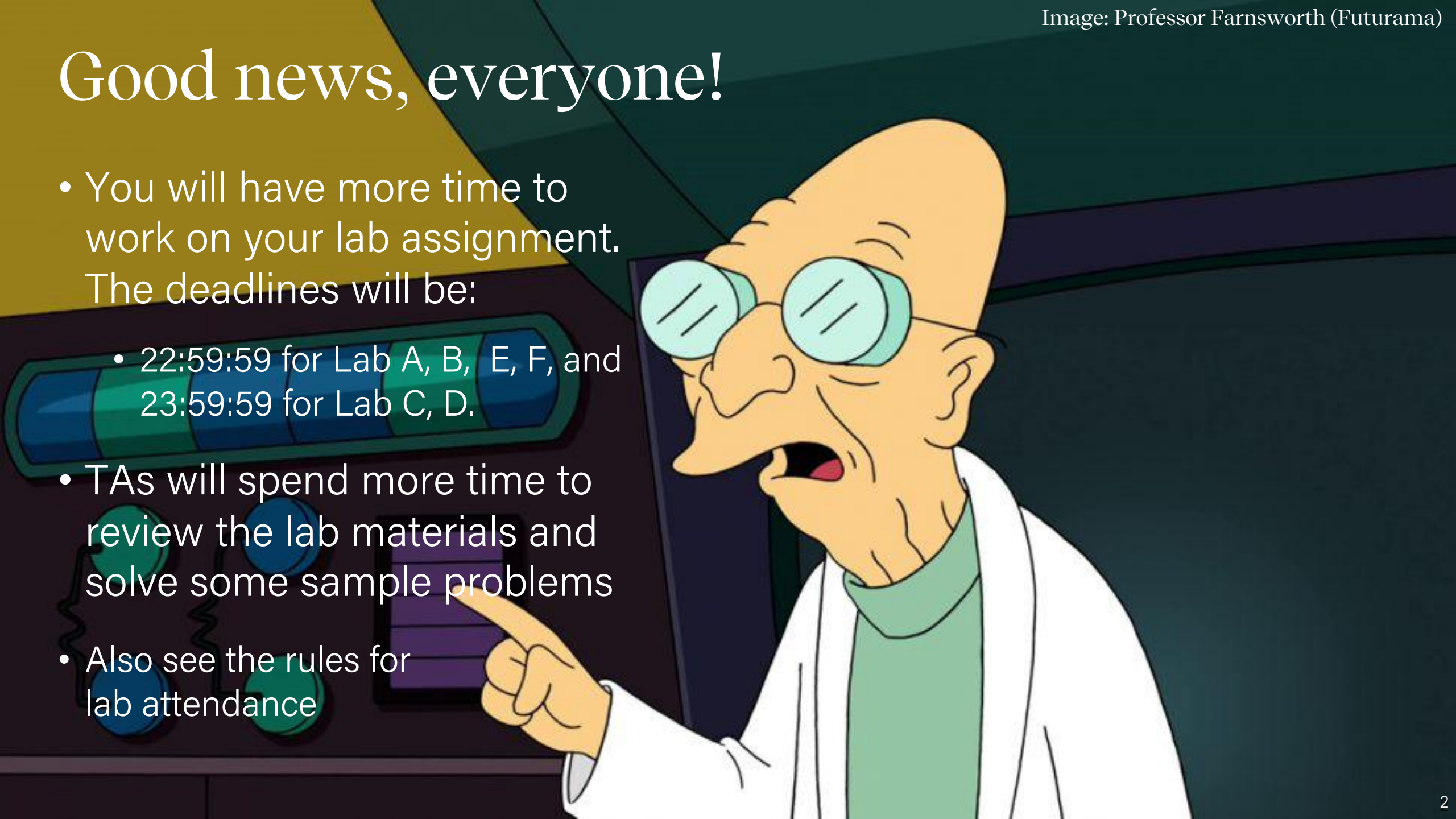


Image: Professor Farnsworth (Futurama)


Deadlines are closer than
they appear in syllabus!

Plan for Today

- Printing the value of a pointer
- Strings in Memory

Disclaimer: Slides for this lecture were borrowed from

—Nick Troccoli's Stanford CS107 class

Lecture Plan

- Printing the value of a pointer
- Strings in Memory

Practice: Printing the value of a pointer

`pointer.c`

Lecture Plan

- Printing the value of a pointer
- Strings in Memory

Strings In Memory

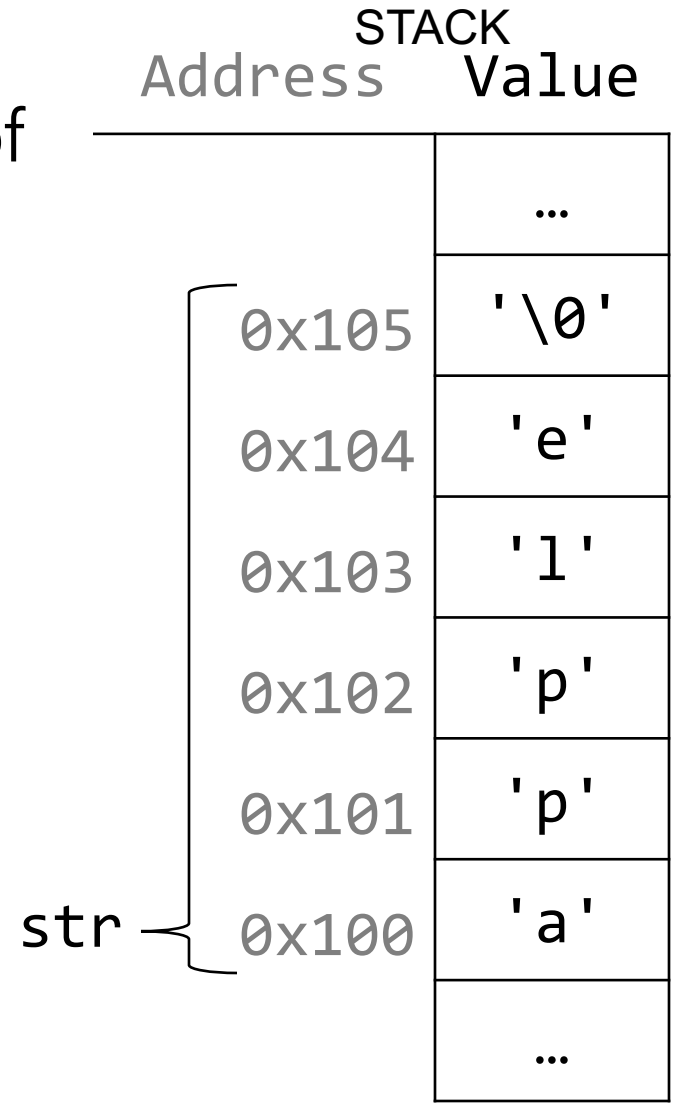
1. If we create a string as a **`char[]`**, we can modify its characters because its memory lives in our stack space.
2. We cannot set a **`char[]`** equal to another value, because it is not a pointer; it refers to the block of memory reserved for the original array.
3. If we pass a **`char[]`** as 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.

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");
```



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!
```

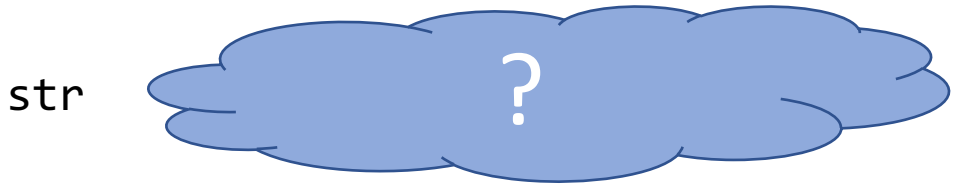
An array's size cannot be changed once we create it; we must create another new array instead.

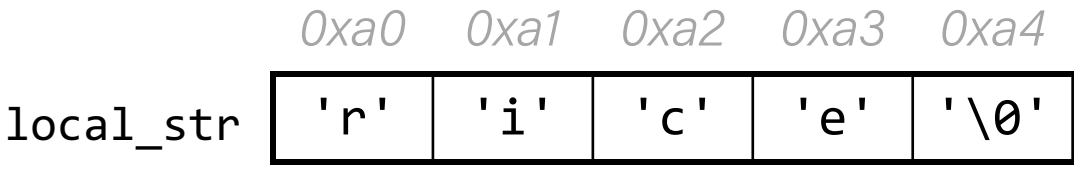
String Behavior #3: If we pass a **`char[]`** as a parameter, set something equal to it, or perform arithmetic with it, it's automatically converted to a **`char *`**.

String Parameters

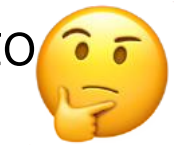
How do you think the parameter `str` is being represented?

```
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;
}
```





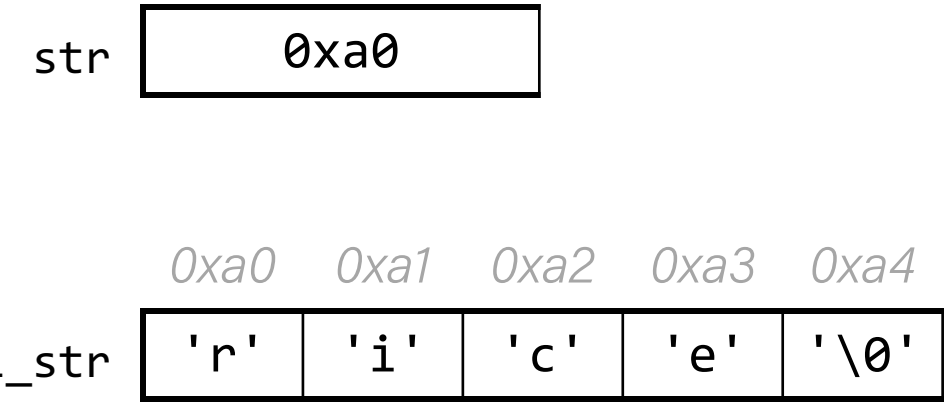
A. A copy of the array `local_str`
B. A pointer containing an address to the first element in `local_str`



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;
}
```



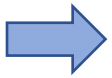
A. A copy of the array `local_str`

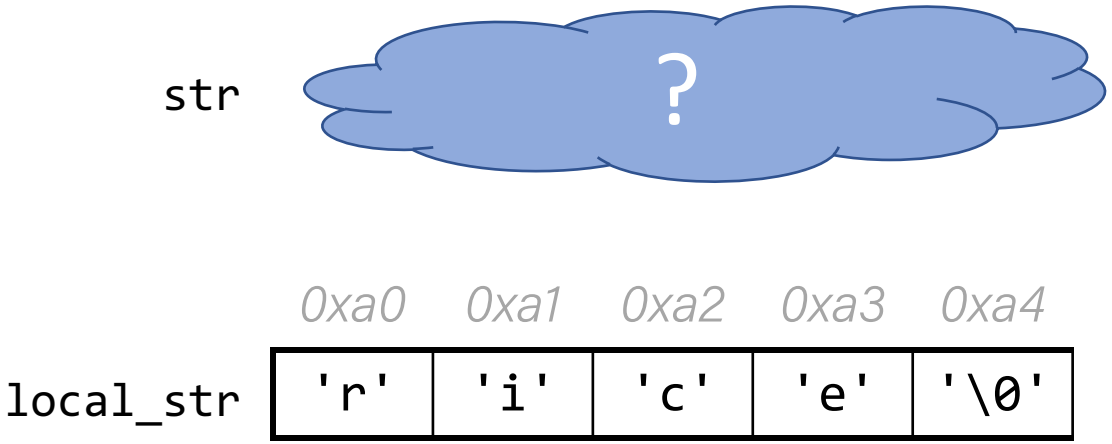
B. A pointer containing an address to the first element in `local_str`

char * Variables

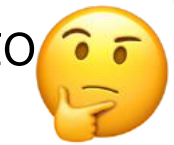
How do you think the local variable `str` is being represented?

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





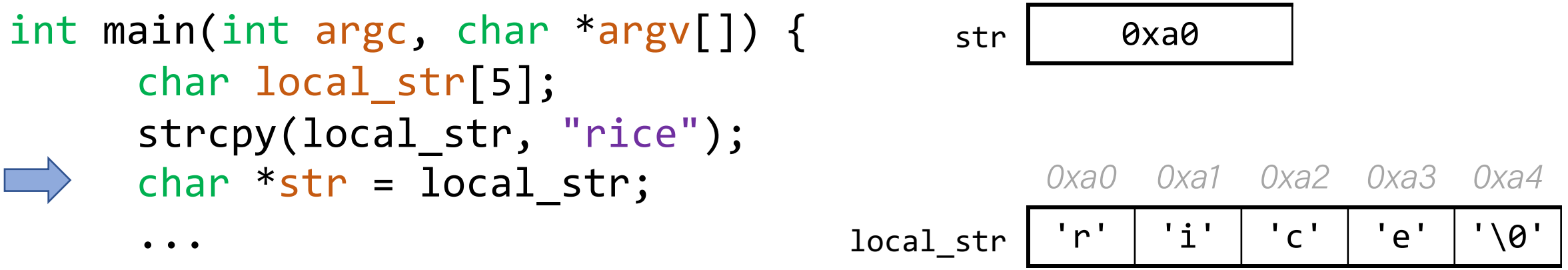
A. A copy of the array `local_str`
B. A pointer containing an address to the first element in `local_str`



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;
}
```

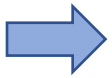


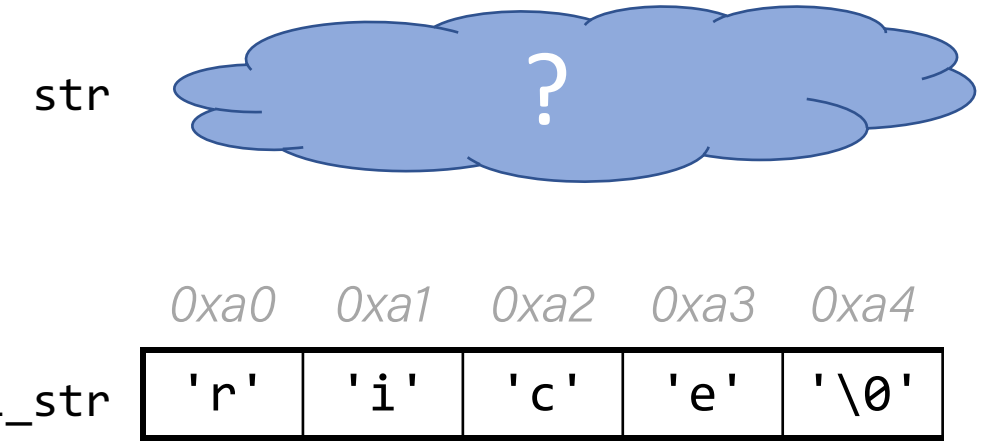
A. A copy of the array `local_str`
B. A pointer containing an address to the first element in `local_str`

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;
}
```



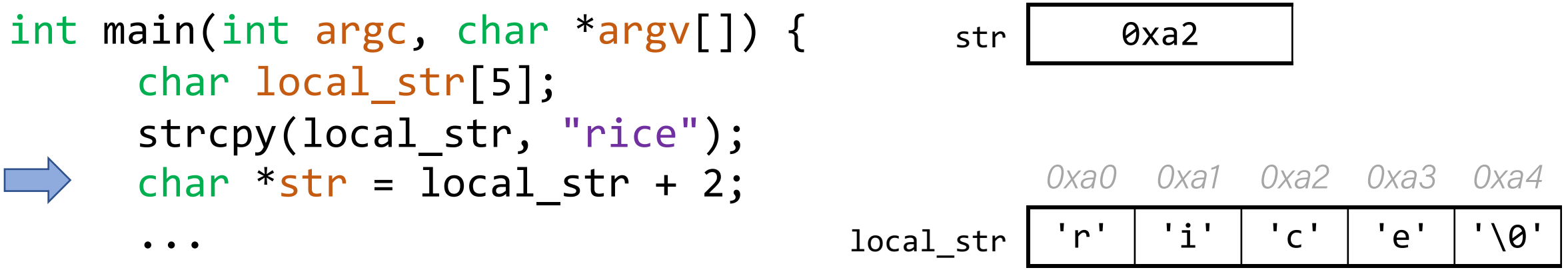


A. A copy of part of the array `local_str`
B. A pointer containing an address to the third element in `local_str`

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;
}
```



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.

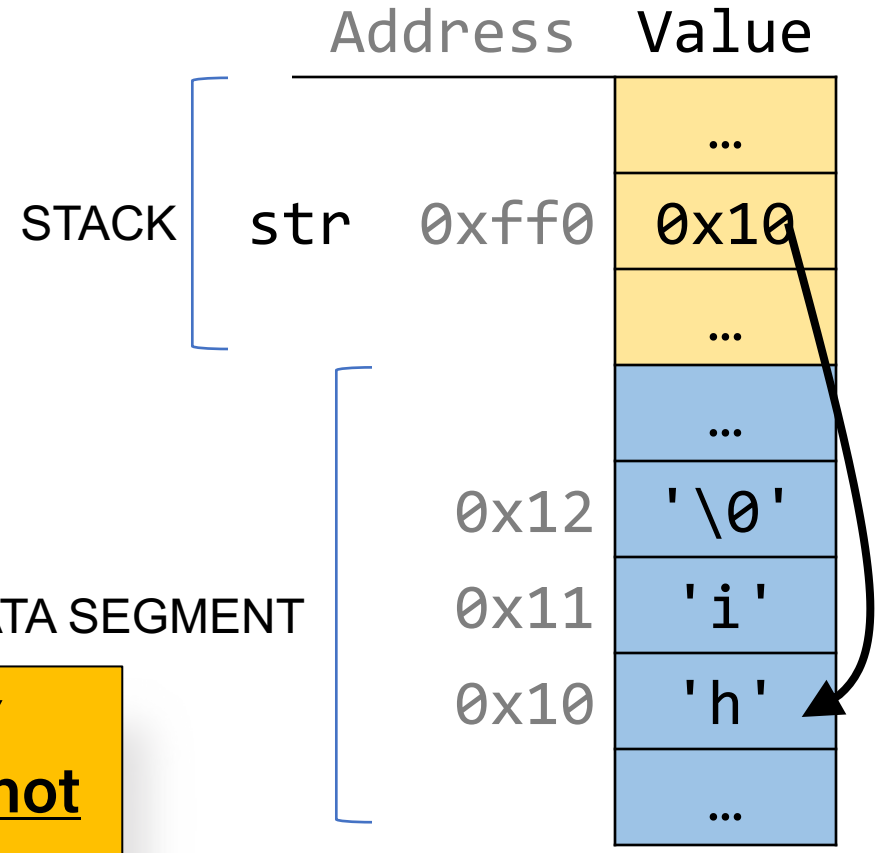
```
char *myString = "Hello, world!";
char *empty = "";

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.*



This applies only to creating *new* strings with `char *`. This does **not** 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`**?

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

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 *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 a reassign-able pointer.

char *

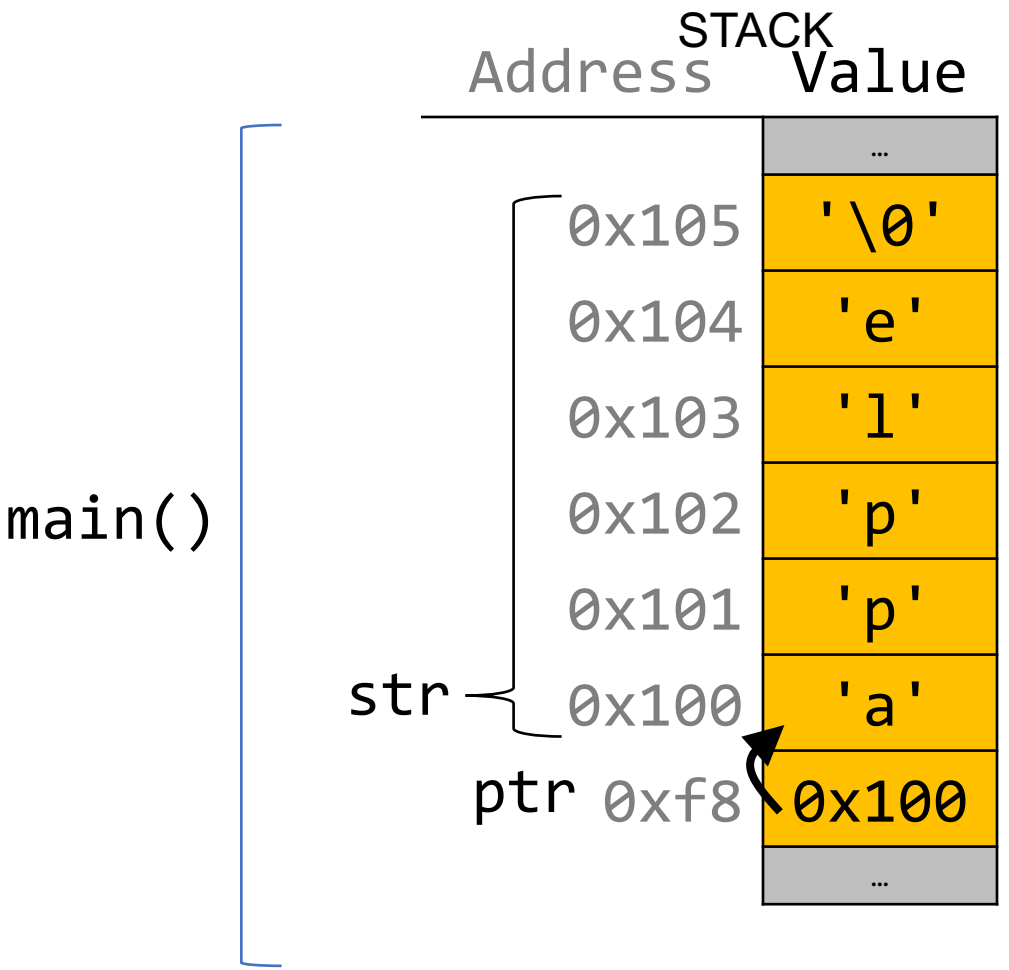
A **char *** variable refers to a single character. We can reassign an existing **char *** pointer to be equal to another **char *** pointer.

```
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.

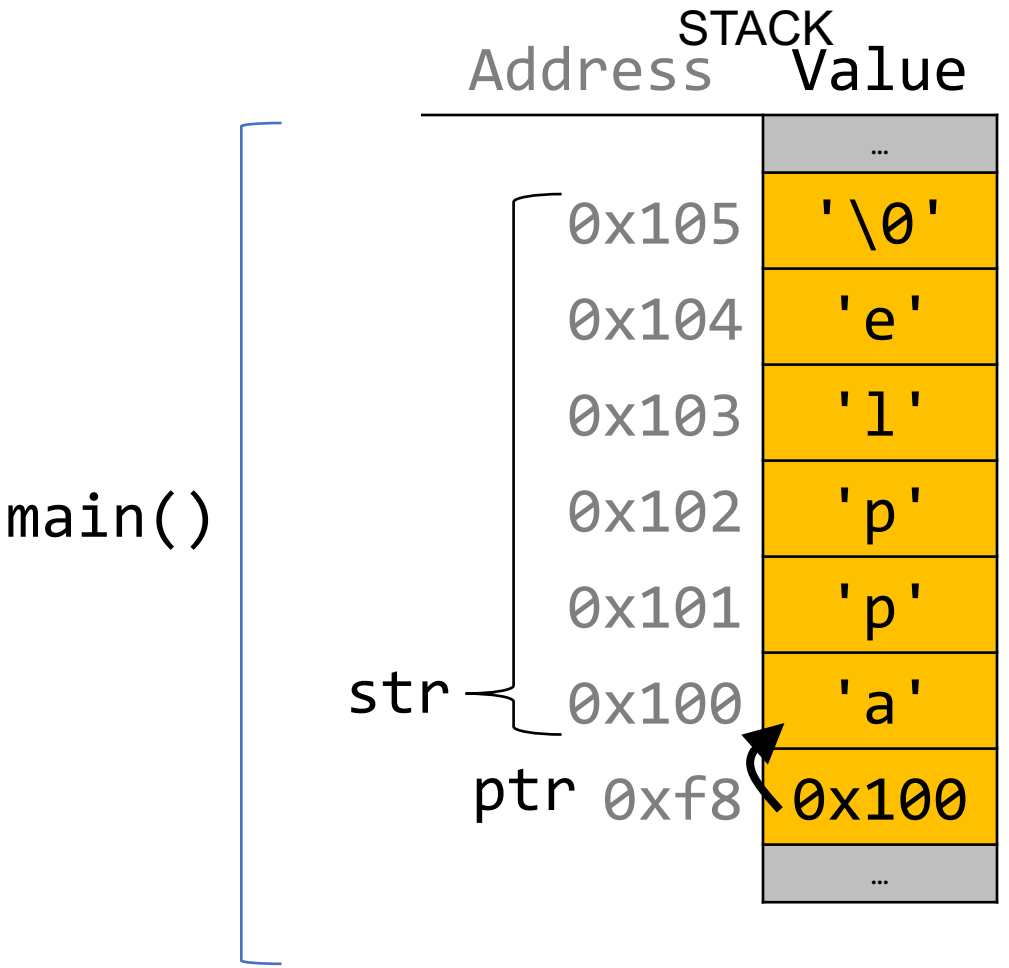
```
int main(int argc, char *argv[]) {
      char str[6];
      strcpy(str, "apple");
      char *ptr = str;
      ...
}
```



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;
      ...
}
```

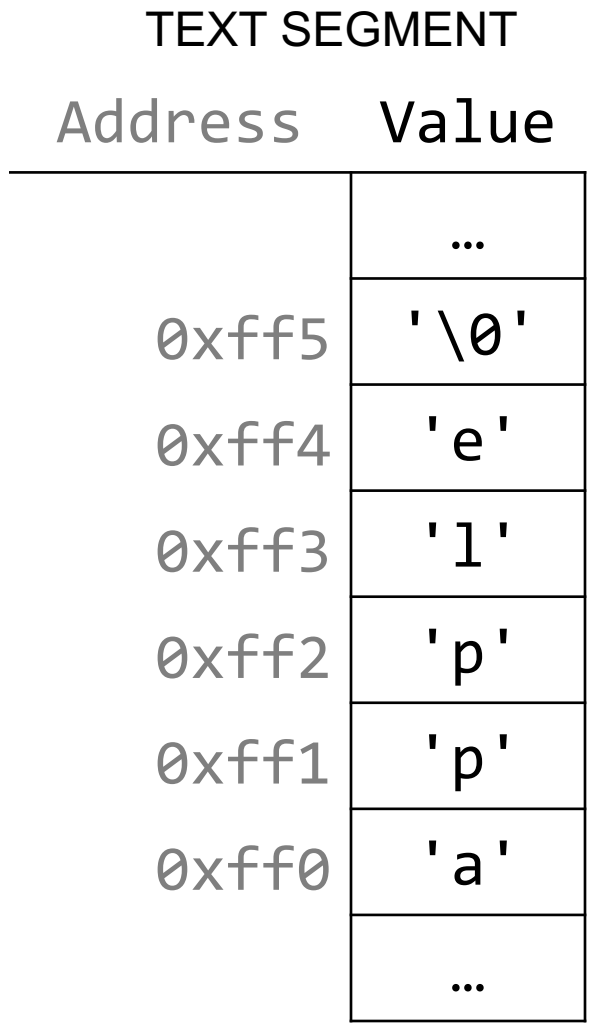


String Behavior #6: Adding an offset to a C string gives us a substring that many places past the first character.

Pointer Arithmetic

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

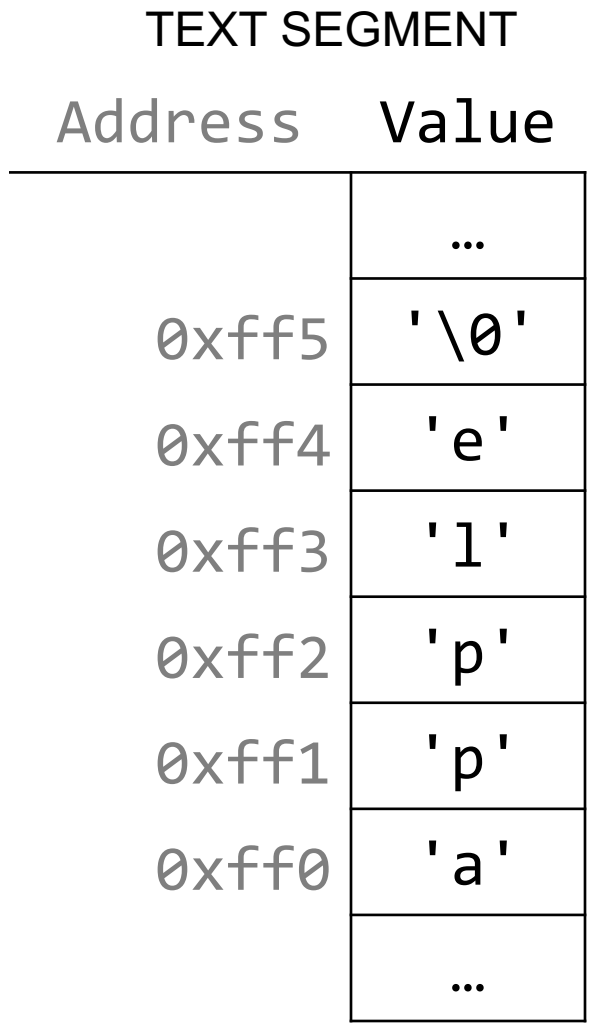
```
char *str = "apple";    // e.g. 0xff0
char *str2 = str + 1;   // e.g. 0xff1
char *str3 = str + 3;   // e.g. 0xff3

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



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 thirdLetter = str[3];        // 'l'
char thirdLetter = *(str + 3);    // 'l'
```

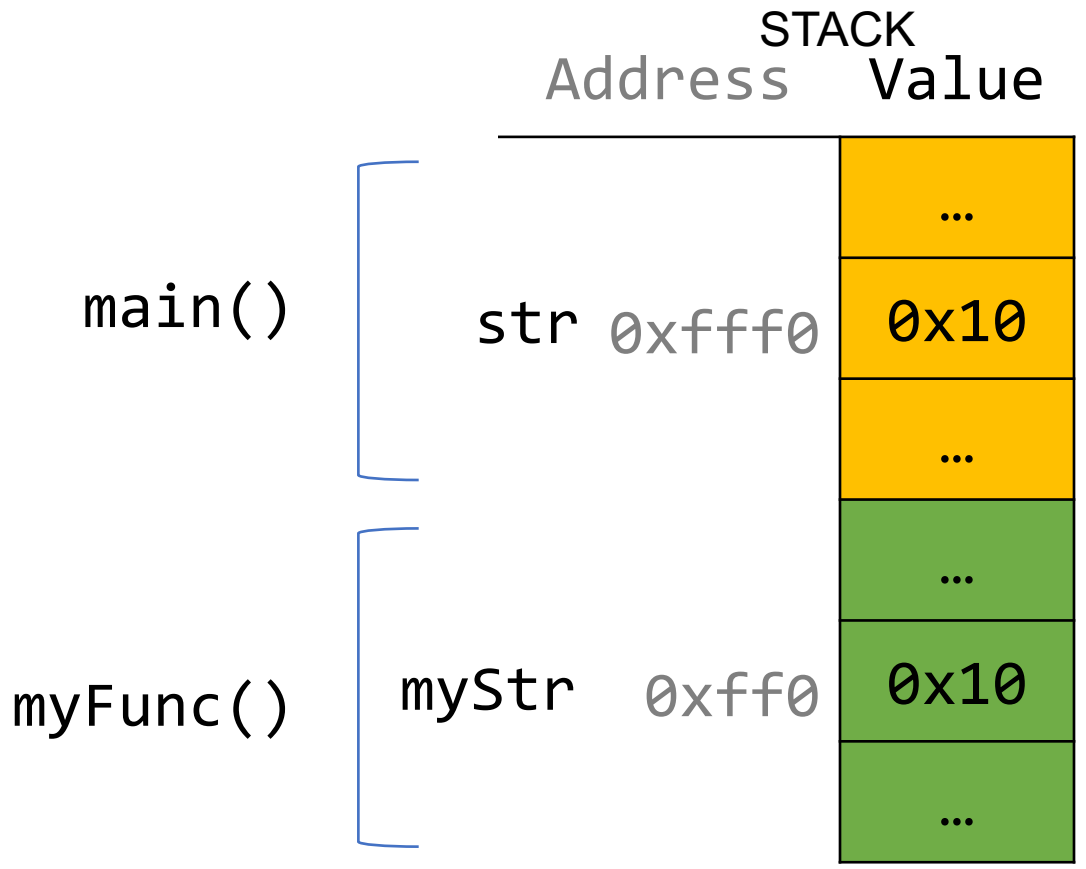


String Behavior #7: If we change characters in a string parameter, these changes will persist outside of the function.

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.

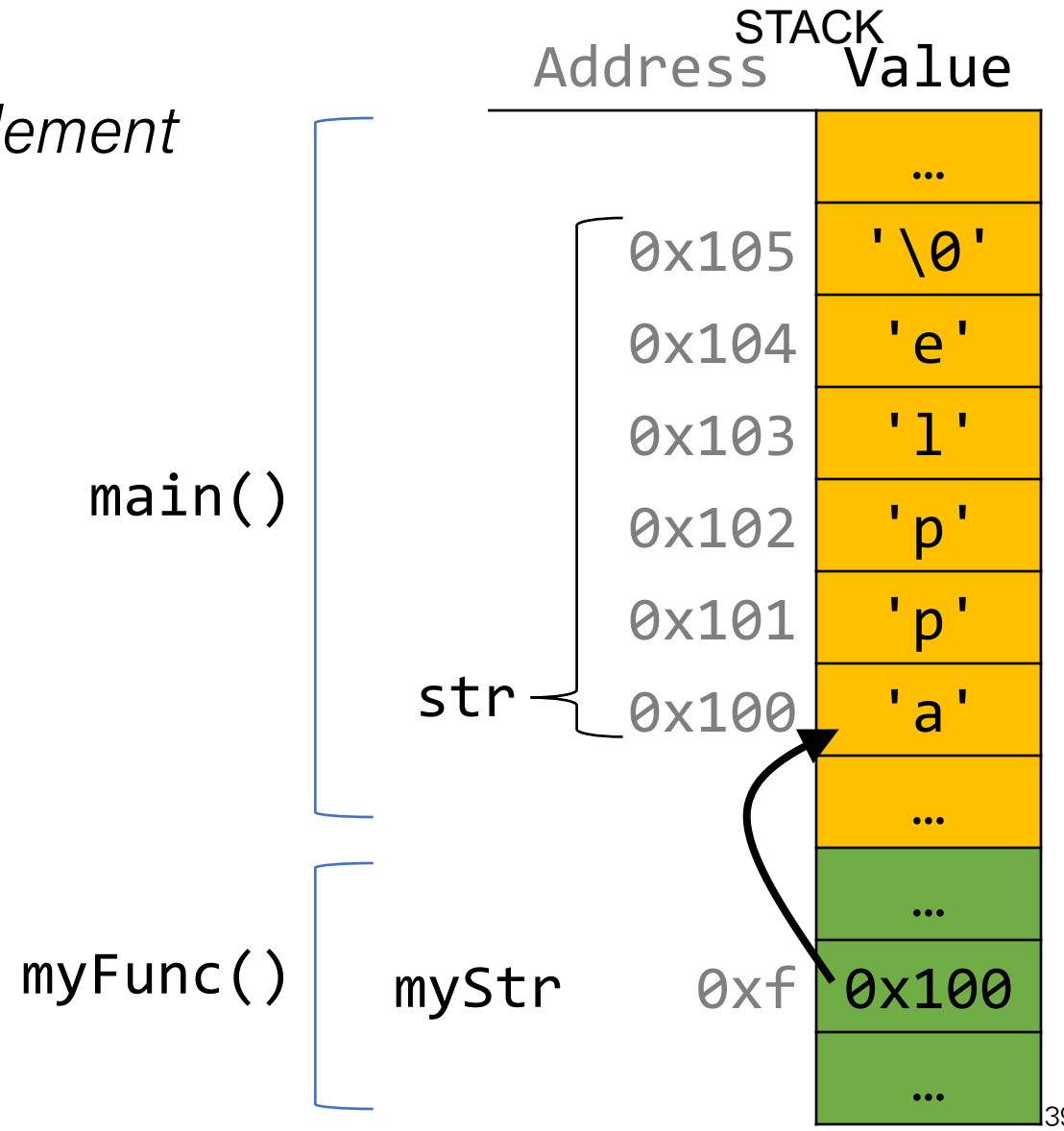
```
void myFunc(char *myStr) {
      ...
}

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.

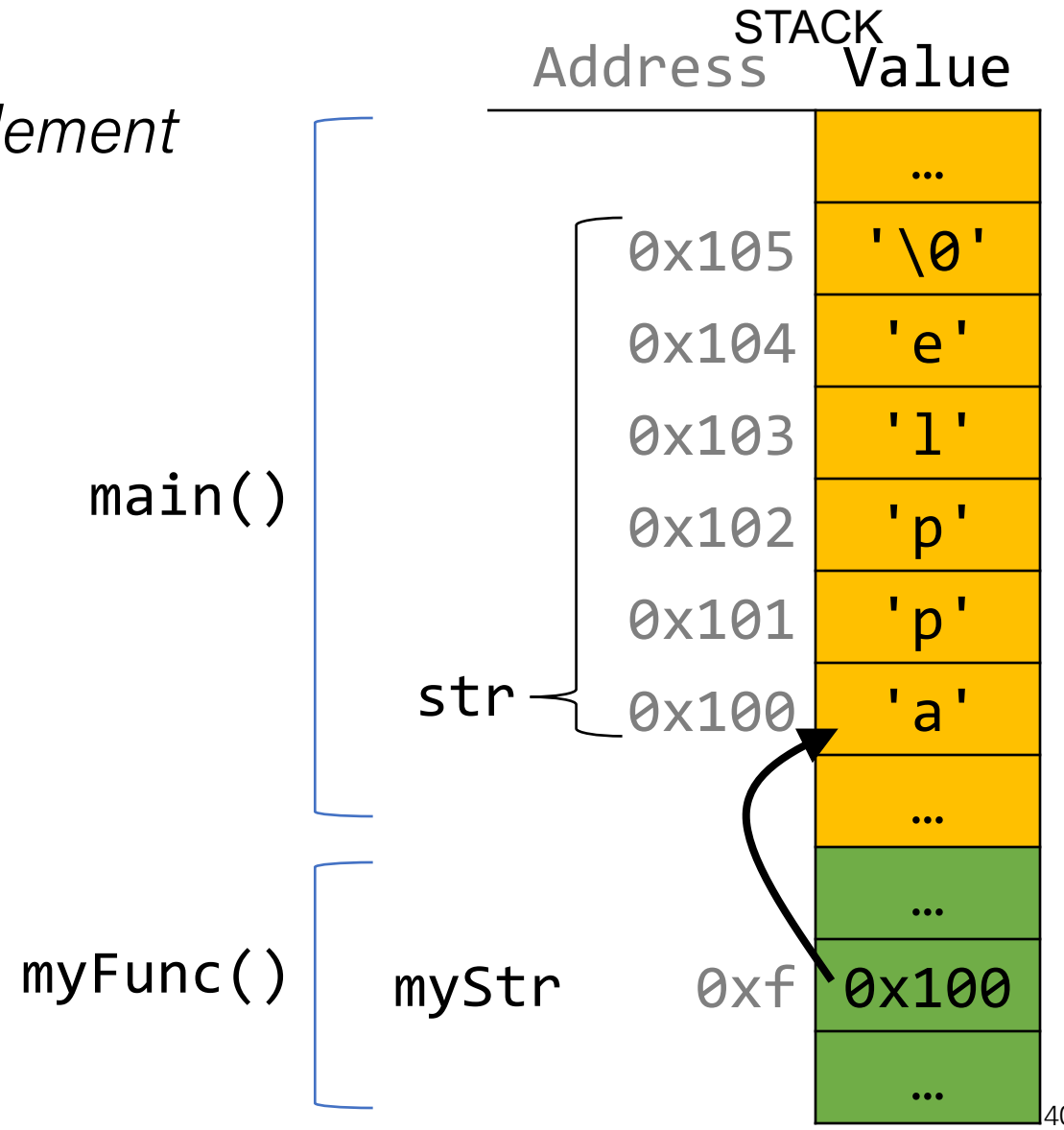
```
void myFunc(char *myStr) {
      ...
}

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



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.

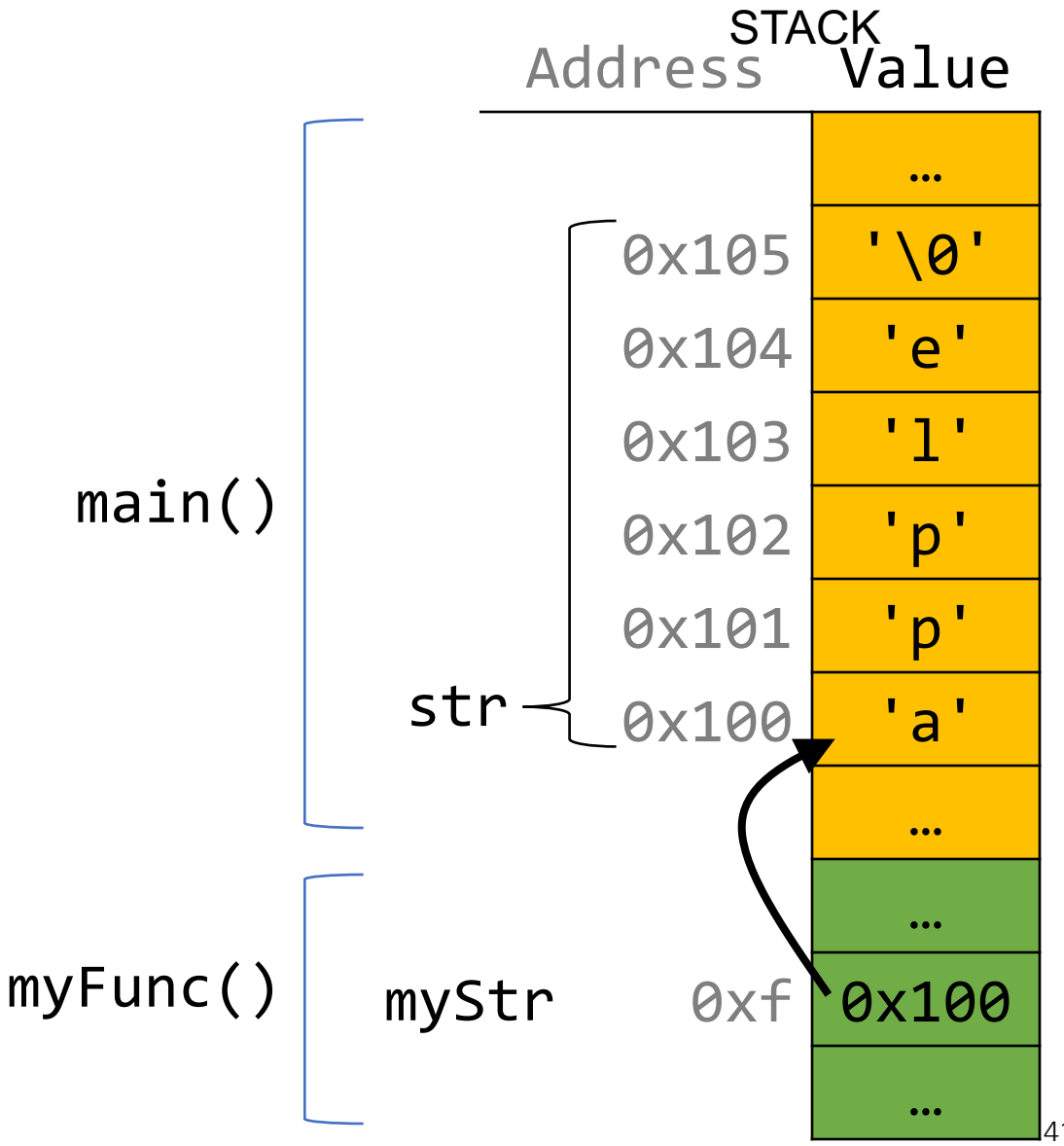
```
void myFunc(char *myStr) {
      ...
}

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**!

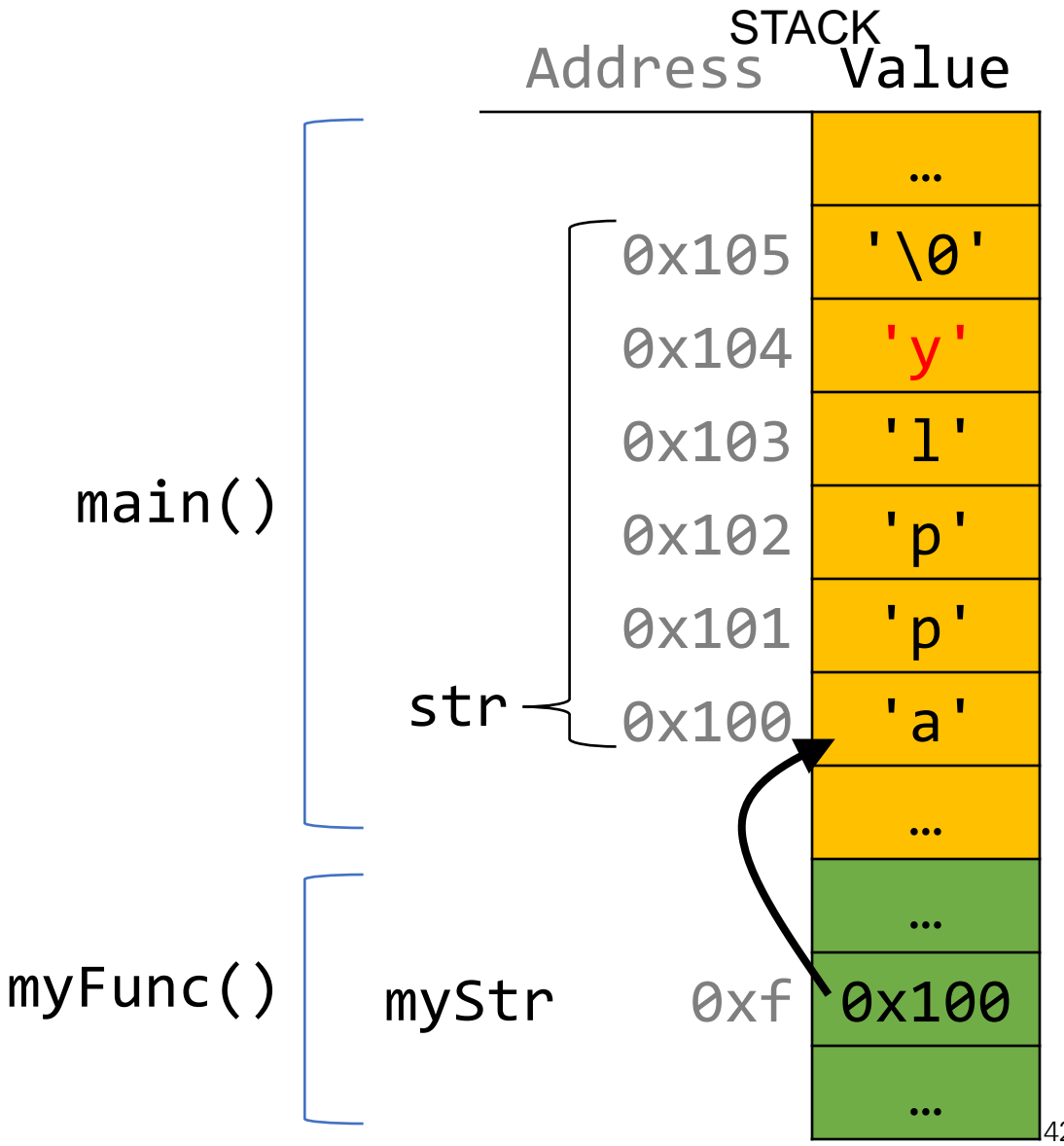
```
void myFunc(char *myStr) {
      myStr[4] = 'y';
}

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



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
      ...
}
```



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.
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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.

Practice

`char*` vs `char[]` exercises

Suppose we use a variable `str` as follows:

```
str = str + 1;
str[1] = 'u';
printf("%s", str)
```

For each of the following instantiations:

- Will there be a compile error/segfault?
- If no errors, what is printed?

1.
```
char str[7];
strcpy(str, "Hello1");
```

`char*` vs `char[]` exercises

Suppose we use a variable `str` as follows:

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- Will there be a compile error/segfault?
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```
char str[7];
strcpy(str, "Hello1");
```
Compile error (cannot reassign array)

`char*` vs `char[]` exercises

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char str[7];
strcpy(str, "Hello1");
```
Compile error (cannot reassign array)

2.
```
char *str = "Hello2";
```

`char*` vs `char[]` exercises

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```
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char str[7];
strcpy(str, "Hello1");
```
Compile error (cannot reassign array)

2.
```
char *str = "Hello2";
```
Segmentation fault (string literal)

`char*` vs `char[]` exercises

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char str[7];
strcpy(str, "Hello1");
```
Compile error (cannot reassign array)

2.
```
char *str = "Hello2";
```
Segmentation fault (string literal)

3.
```
char arr[7];
strcpy(arr, "Hello3");
char *str = arr;
```

char* vs char[] exercises

Suppose we use a variable `str` as follows:

```
str = str + 1;
str[1] = 'u';
printf("%s", str)
```

For each of the following instantiations:

- Will there be a compile error/segfault?
- If no errors, what is printed?

1.
```
char str[7];
strcpy(str, "Hello1");
```
Compile error (cannot reassign array)

2.
```
char *str = "Hello2";
```
Segmentation fault (string literal)

3.
```
char arr[7];
strcpy(arr, "Hello3");
char *str = arr;
```
Prints eulo3

`char*` vs `char[]` exercises

Suppose we use a variable `str` as follows:

```
str = str + 1;
str[1] = 'u';
printf("%s", str)
```

For each of the following instantiations:

- Will there be a compile error/segfault?
- If no errors, what is printed?

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char str[7];
strcpy(str, "Hello1");
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Compile error (cannot reassign array)

2.
```
char *str = "Hello2";
```
Segmentation fault (string literal)

3.
```
char arr[7];
strcpy(arr, "Hello3");
char *str = arr;
```
Prints eulo3

4.
```
char *ptr = "Hello4";
char *str = ptr;
```

`char*` vs `char[]` exercises

Suppose we use a variable `str` as follows:

```
str = str + 1;
str[1] = 'u';
printf("%s", str)
```

For each of the following instantiations:

- Will there be a compile error/segfault?
- If no errors, what is printed?

1.
```
char str[7];
strcpy(str, "Hello1");
```
Compile error (cannot reassign array)

2.
```
char *str = "Hello2";
```
Segmentation fault (string literal)

3.
```
char arr[7];
strcpy(arr, "Hello3");
char *str = arr;
```
Prints eulo3

4.
```
char *ptr = "Hello4";
char *str = ptr;
```
Segmentation fault (string literal)

Recap

- Printing the value of a pointer
- Strings in Memory

Next time: Arrays and Pointers