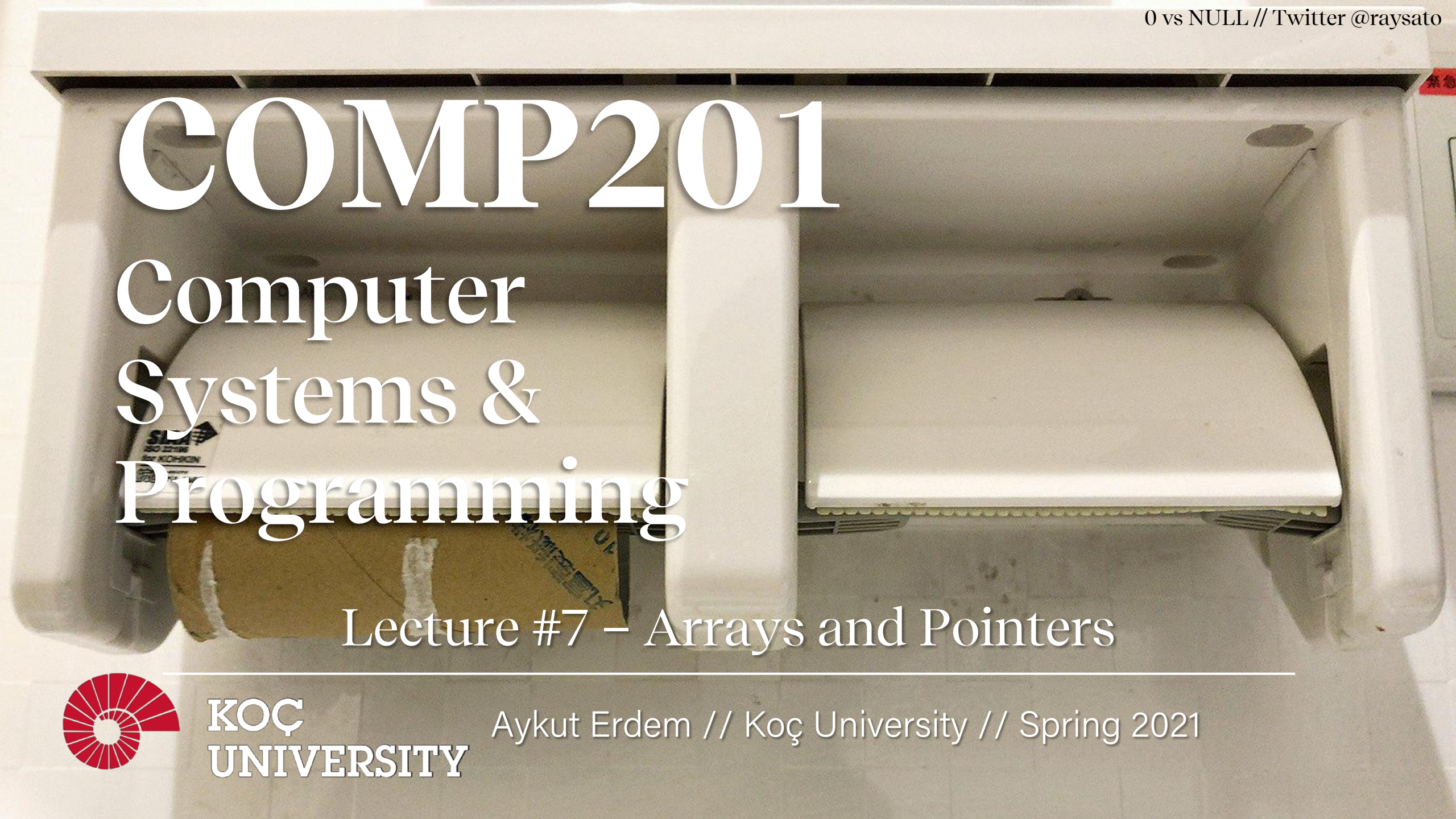


COMP201

Computer Systems & Programming

Lecture #7 – Arrays and Pointers

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Spring 2021

Good news, everyone!

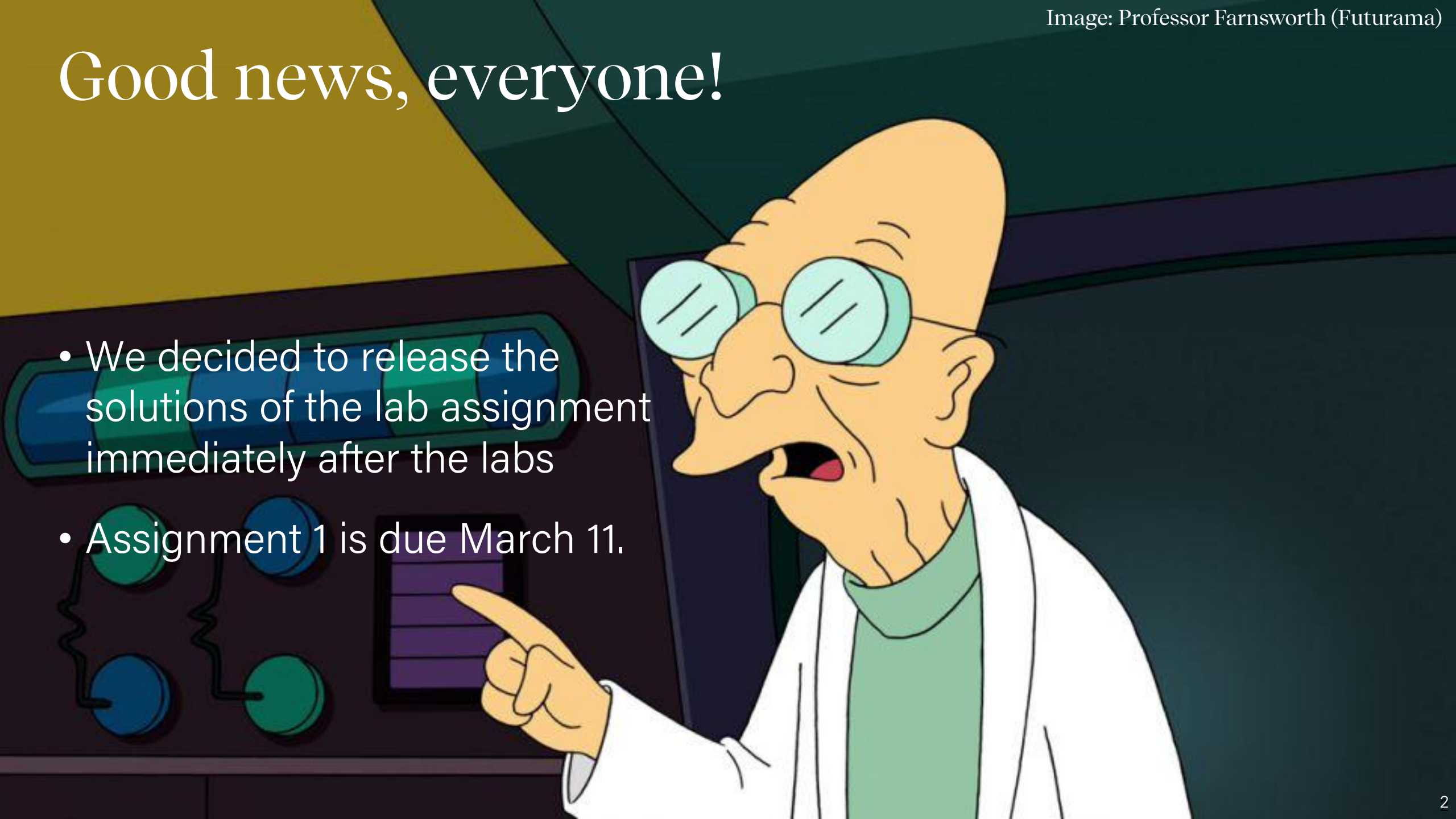


Image: Professor Farnsworth (Futurama)

- We decided to release the solutions of the lab assignment immediately after the labs
- Assignment 1 is due March 11.

COMP201 Topic 4: How can we effectively manage all types of memory in our programs?

Plan for Today

- Pointers and Parameters
- Double Pointers
- Arrays in Memory
- Arrays of Pointers
- Pointer Arithmetic

Disclaimer: Slides for this lecture were borrowed from
—Nick Troccoli and Lisa Yan's Stanford CS107 class

Lecture Plan

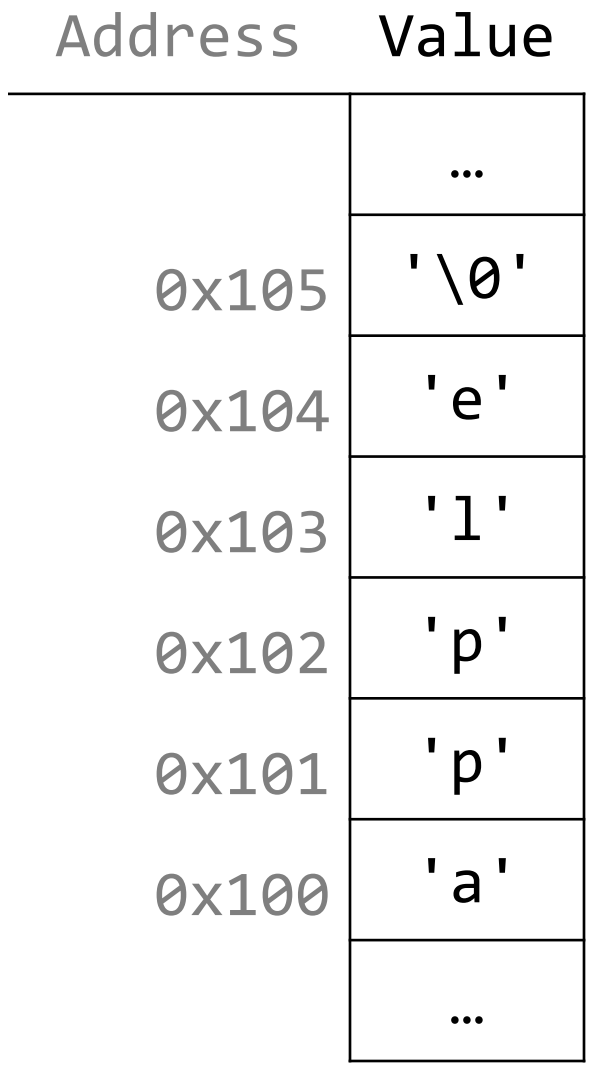
- Pointers and Parameters
- Double Pointers
- Arrays in Memory
- Arrays of Pointers
- Pointer Arithmetic

Recap: 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 represent 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.

Recap: 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.



Recap: Memory

- Memory is a big array of bytes.
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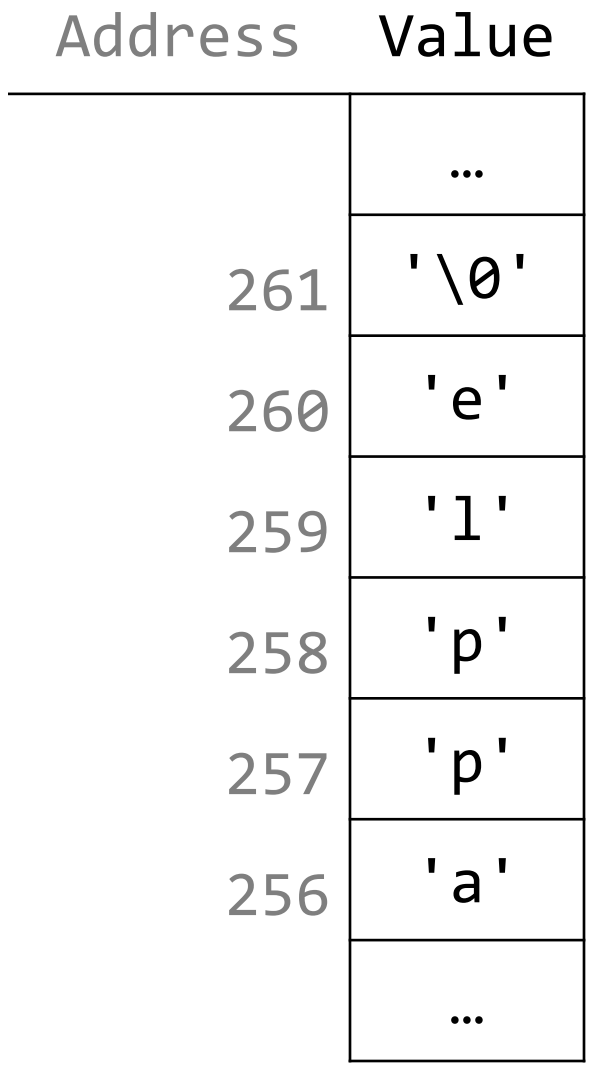


Recap: Pointers

```
int x = 2;


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

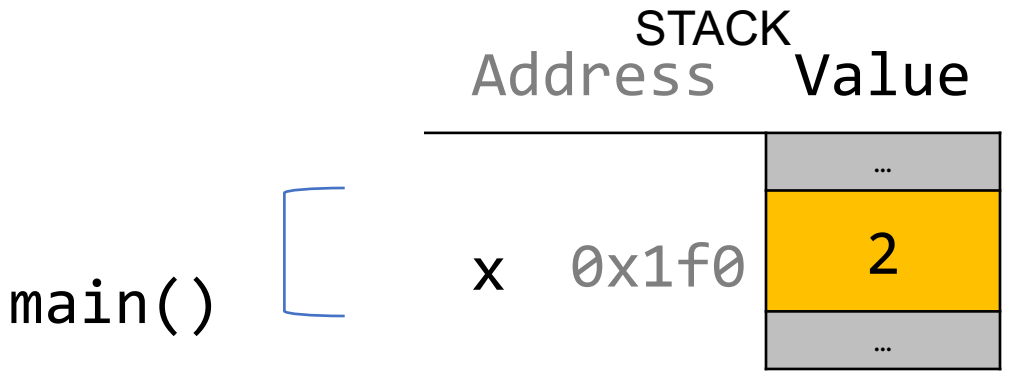

// Dereference the pointer to go to that address.
// (* means "dereference")
printf("%d", *xPtr);    // prints 2
```

Recap: 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!
     ...
}
```

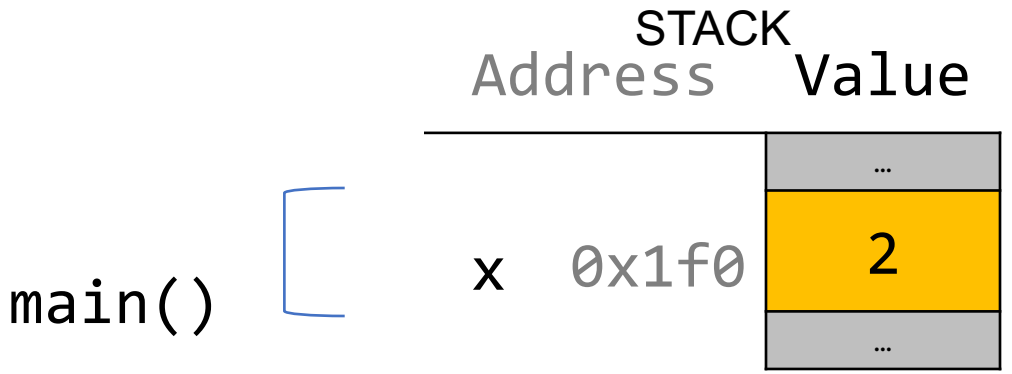


Recap: Pointers

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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A pointer is a variable that stores a memory address.

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}

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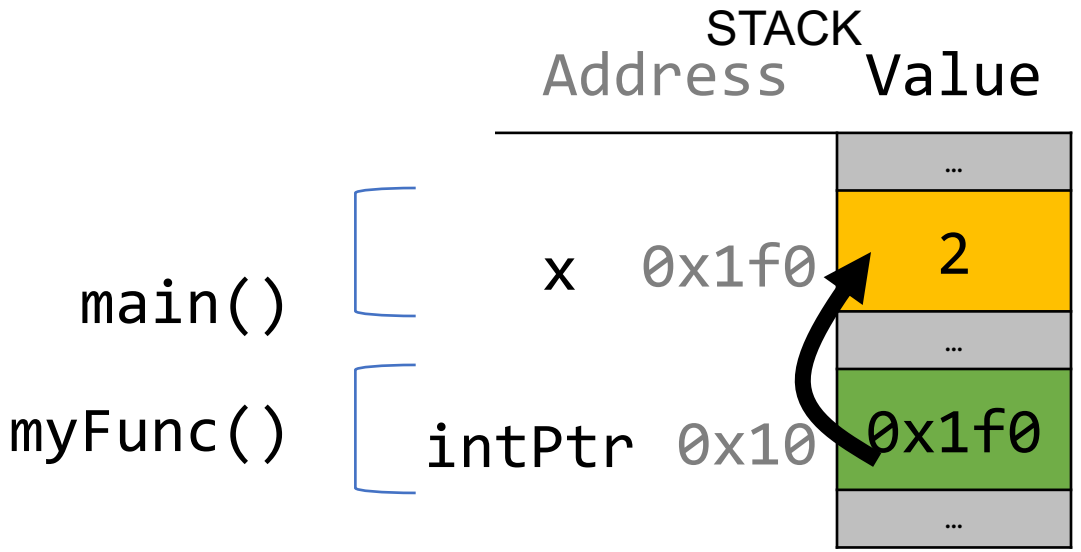
     ...
}
```



Recap: Pointers

A pointer is a variable that stores a memory address.

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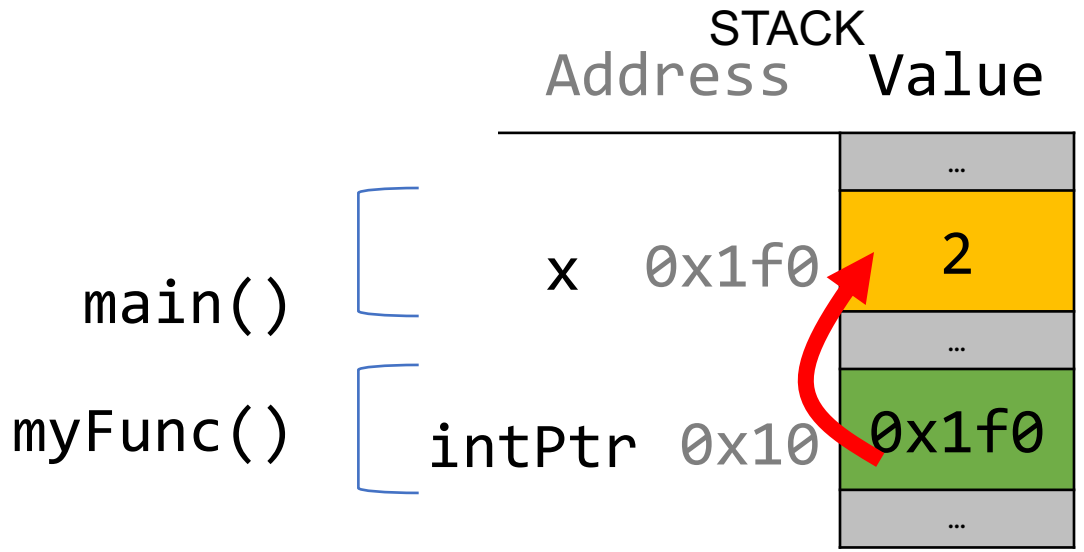
void myFunc(int *intPtr) {
      *intPtr = 3;
}

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

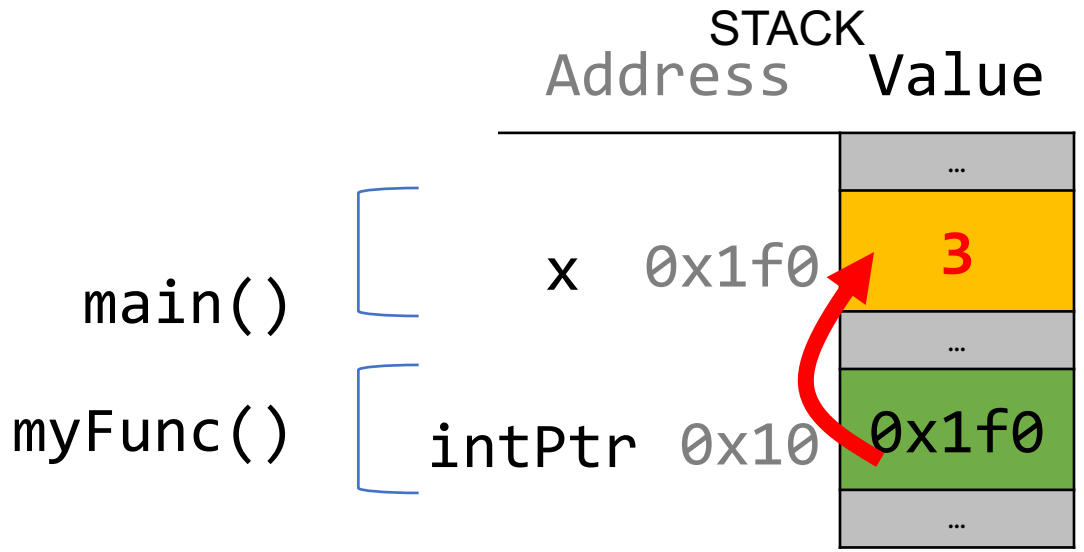


Recap: Pointers

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!
      ...
}
```

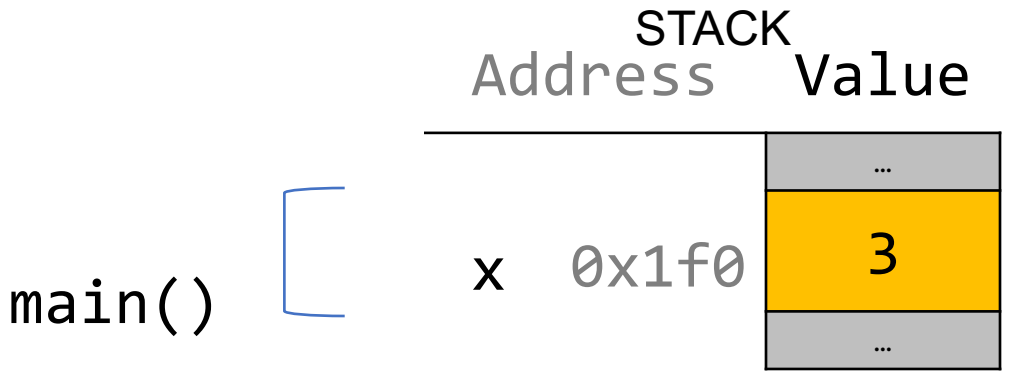


Recap: Pointers

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!
     ...
}
```

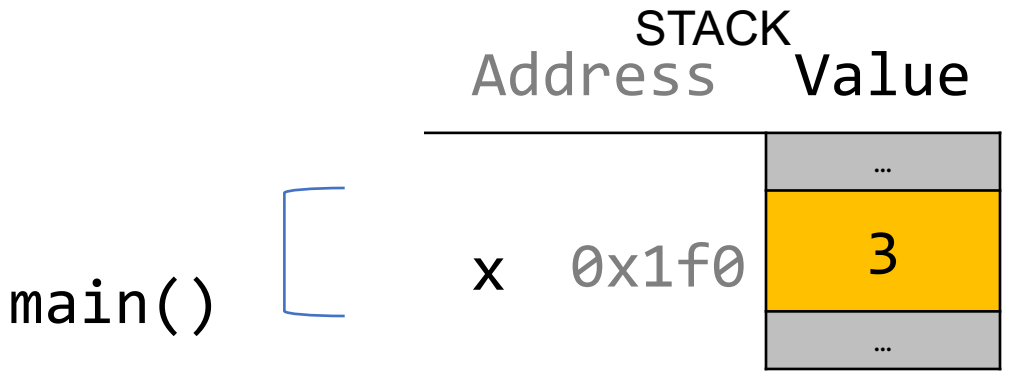


Recap: Pointers

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!
     ...
}
```



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;
}
```

`char *`

- A `char *` is technically a pointer to a **single character**.
- We commonly use `char *` as string by having the character it points to be followed by more characters and ultimately a null terminator.
- A `char *` could also just point to a single character (not a string).

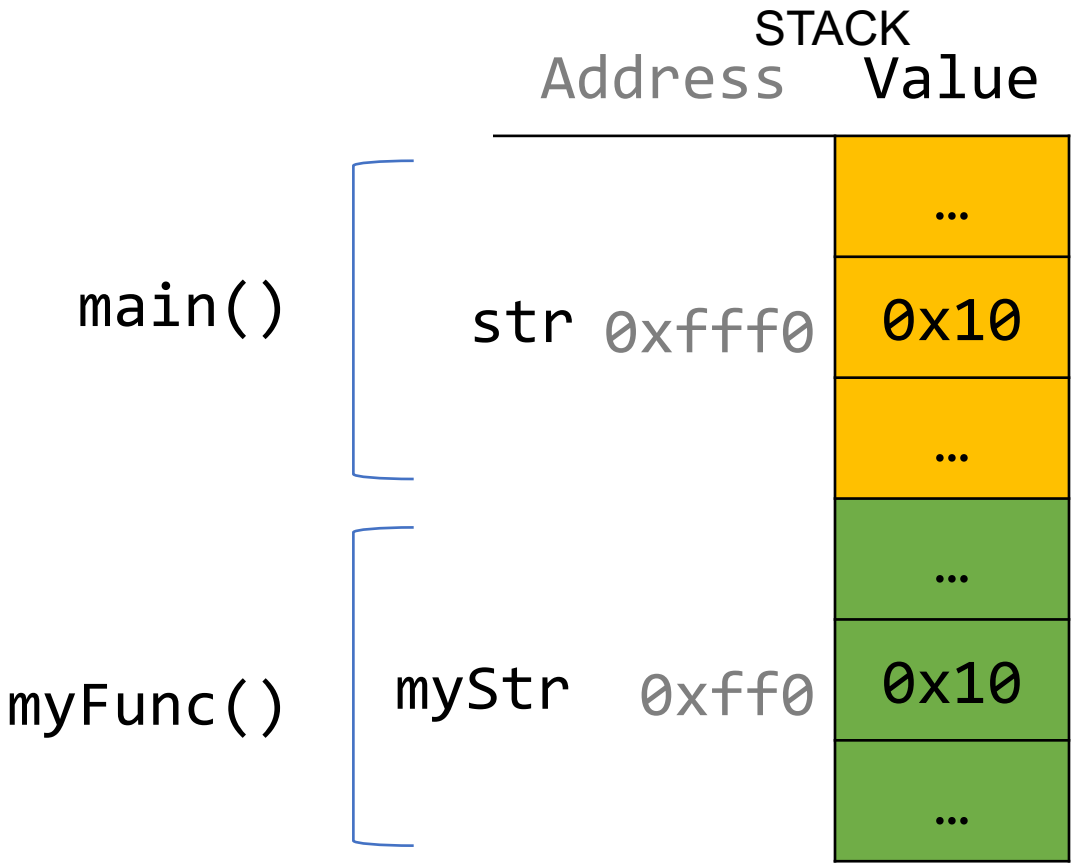
String Behavior #7: If we change characters in a string parameter, these changes will persist outside of the function.

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);
      ...
}
```

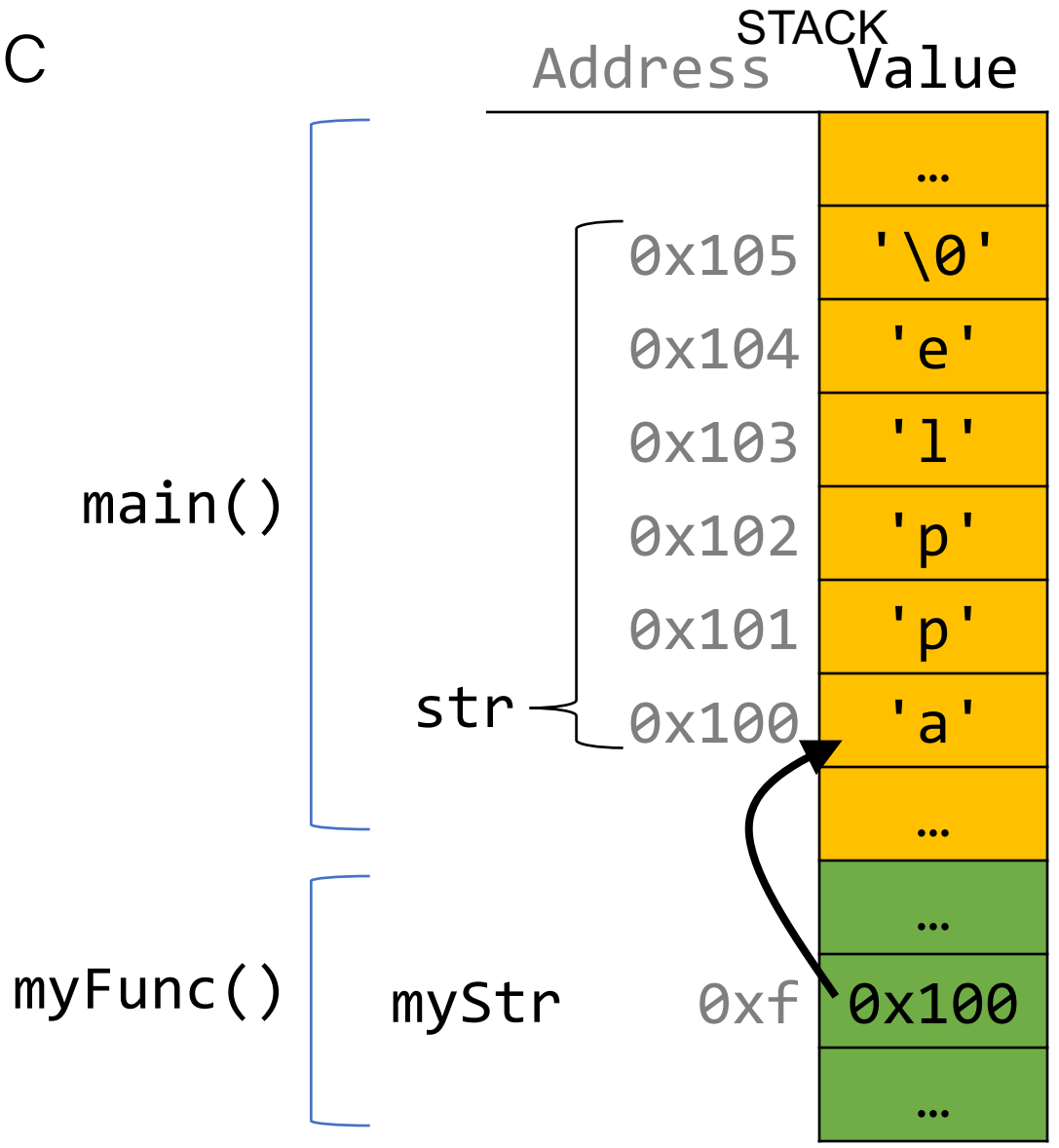


Strings as Parameters

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);
      ...
}
```

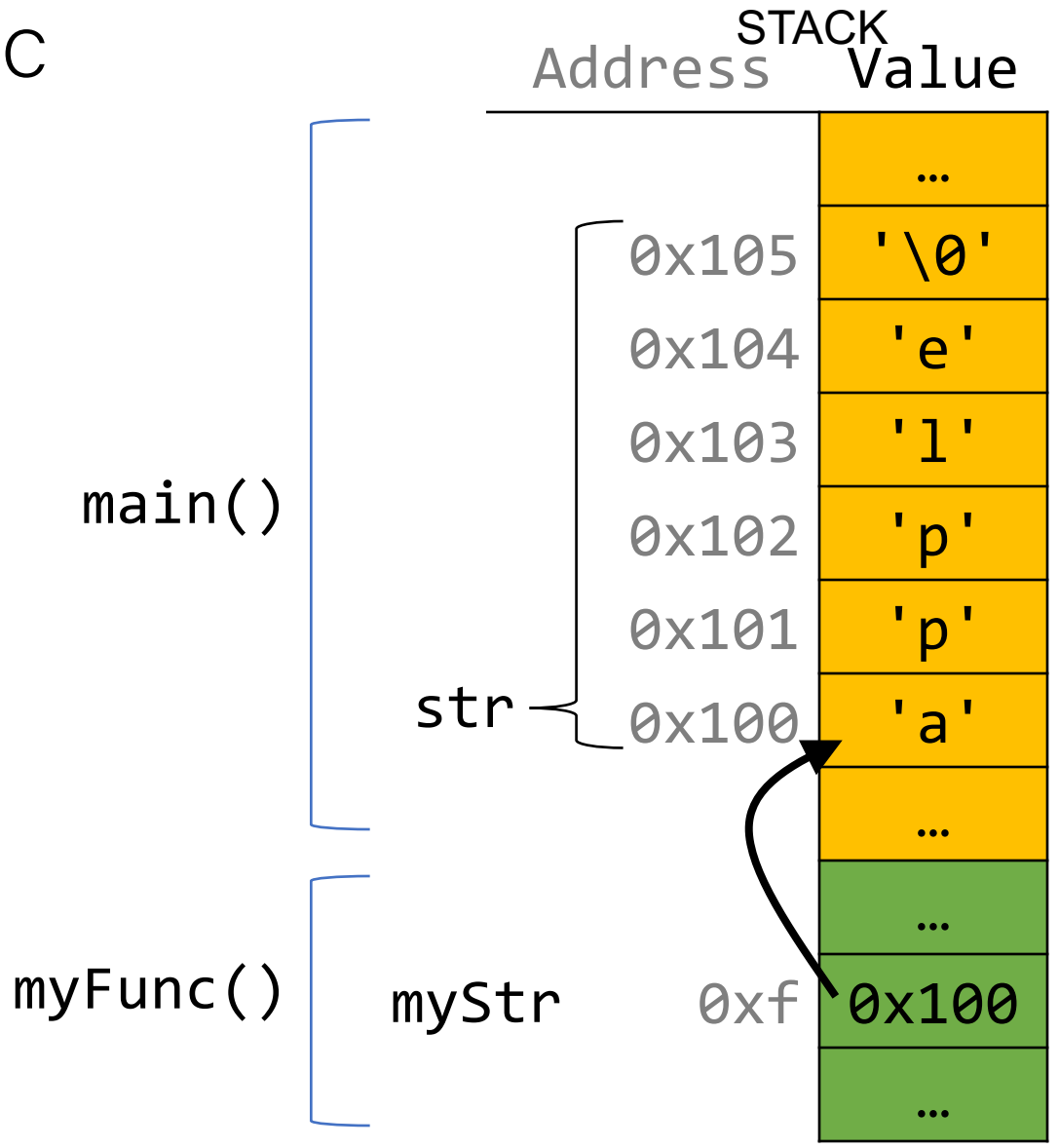


Strings as Parameters

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);
      ...
```

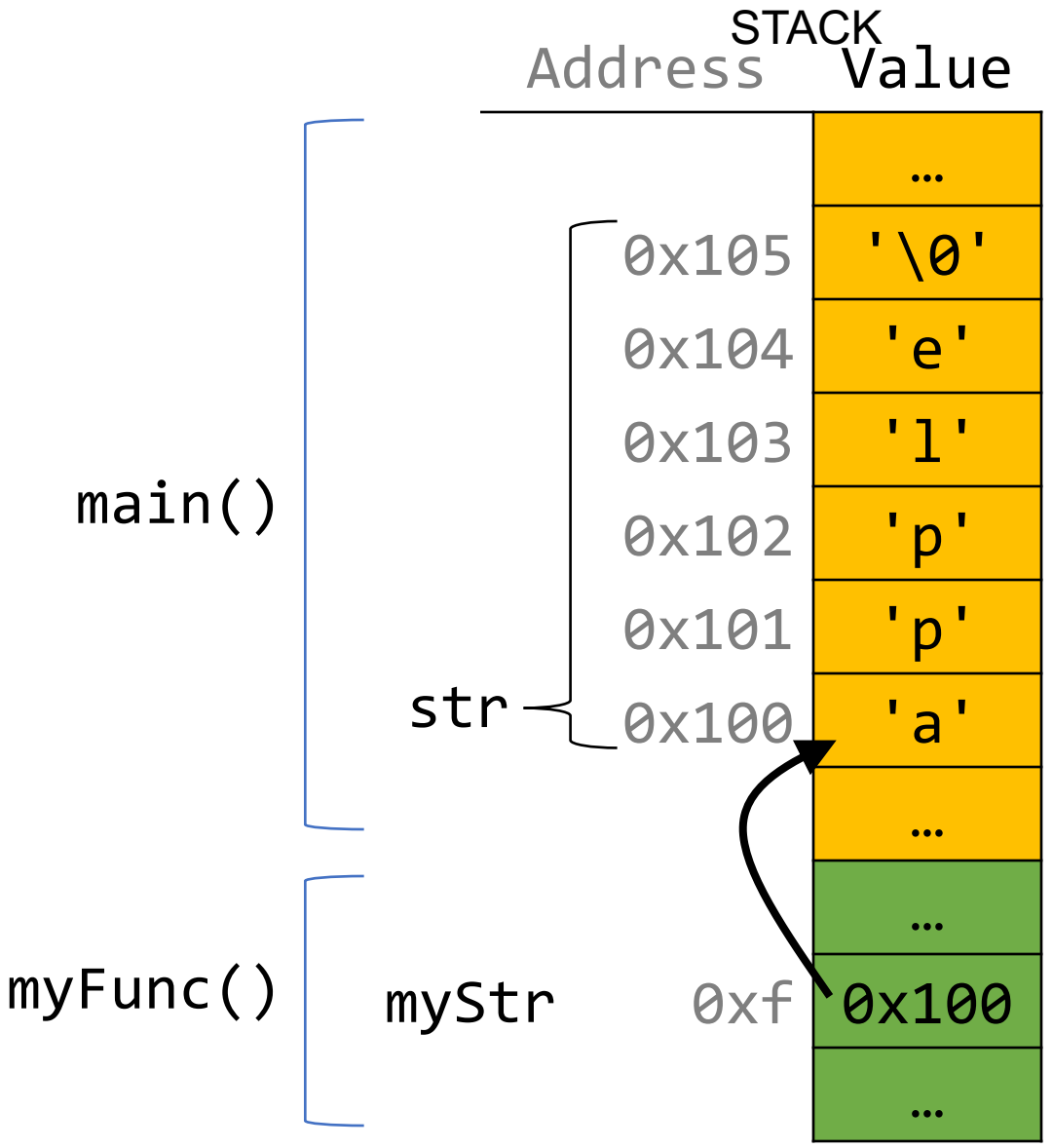


Strings as Parameters

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
      ...
}
```

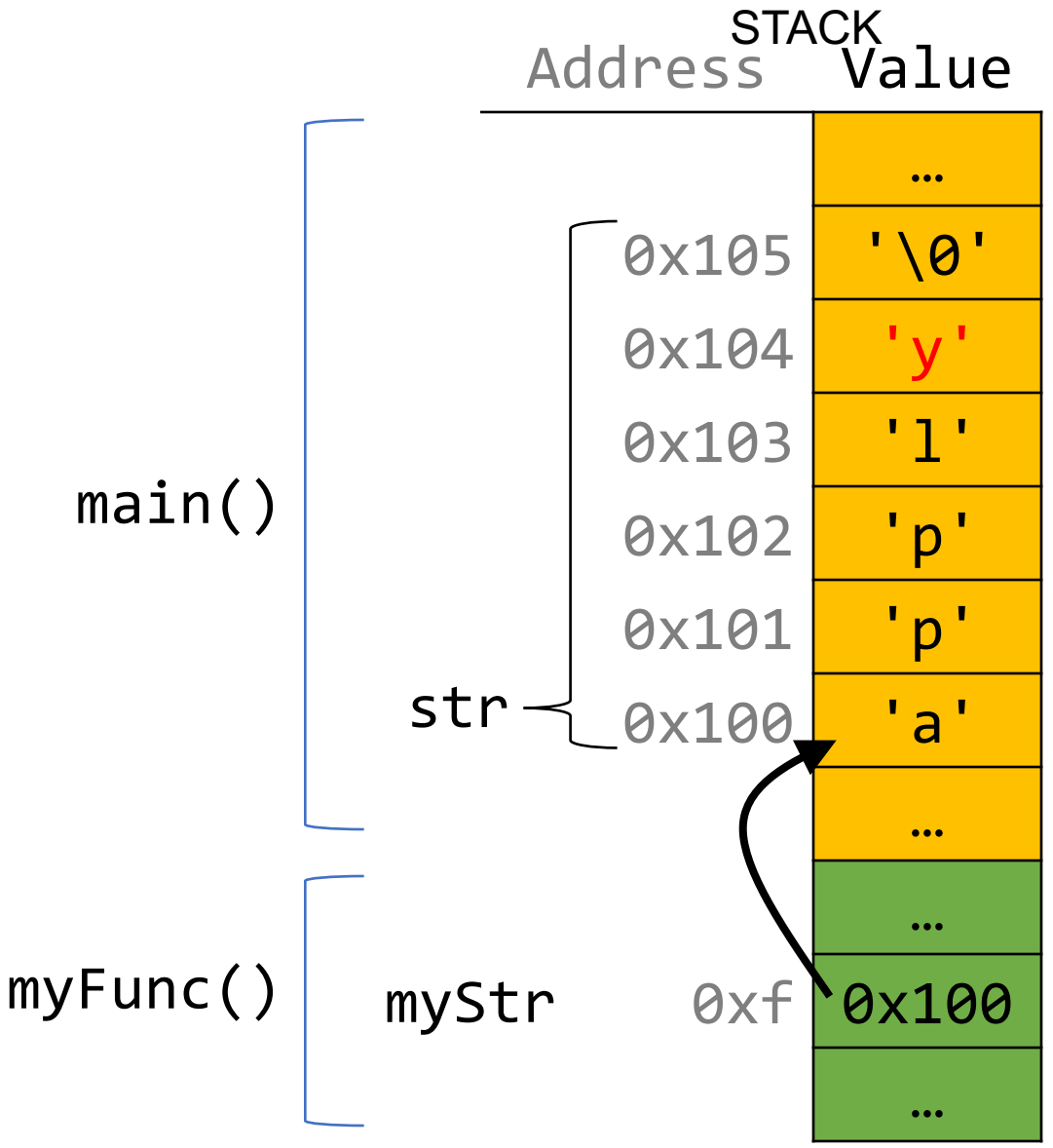


Strings as Parameters

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
      ...
}
```



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!
}
```

Lecture Plan

- Pointers and Parameters
- Double Pointers
- Arrays in Memory
- Arrays of Pointers
- Pointer Arithmetic

Exercise 3

Sometimes, we would like to modify a string's pointer itself, rather than just the characters it points to. E.g. we want to write a function `skipSpaces` that modifies a string pointer to skip past any initial spaces. What should go in each of the blanks?

```
void skipSpaces(__?__) {
    ...
}

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

Exercise 3

Sometimes, we would like to modify a string's pointer itself, rather than just the characters it points to. E.g. we want to write a function `skipSpaces` that modifies a string pointer to skip past any initial spaces. What should go in each of the blanks?

```
void skipSpaces(char **strPtr) {
    ...
}

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

Sometimes, we would like to modify a string's pointer itself, rather than just the characters it points to. E.g. we want to write a function `skipSpaces` that modifies a string pointer to skip past any initial spaces. What should go in each of the blanks?

```
void skipSpaces(char *strPtr) {
     ...
}

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.

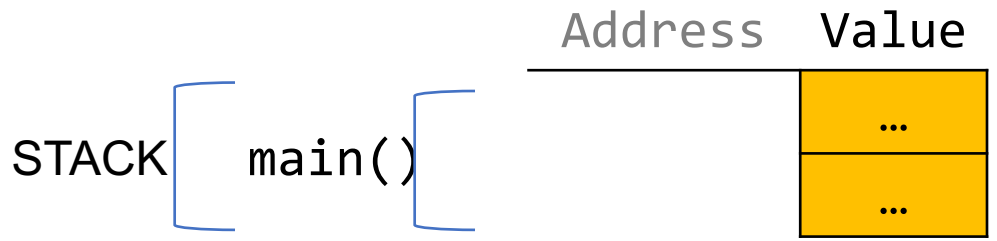
Demo: Skip Spaces

`skip_spaces.c`

Pointers to Strings

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

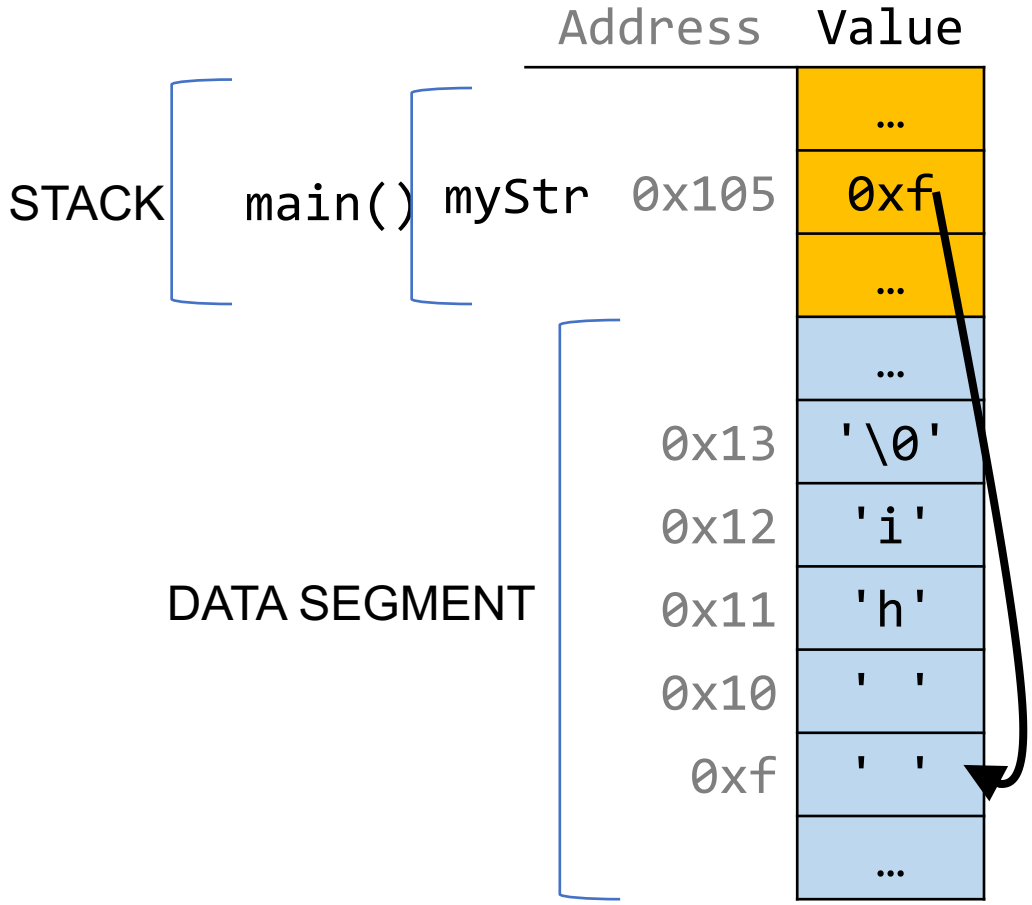
int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



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;
}
```



Pointers to Strings

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

int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
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    return 0;
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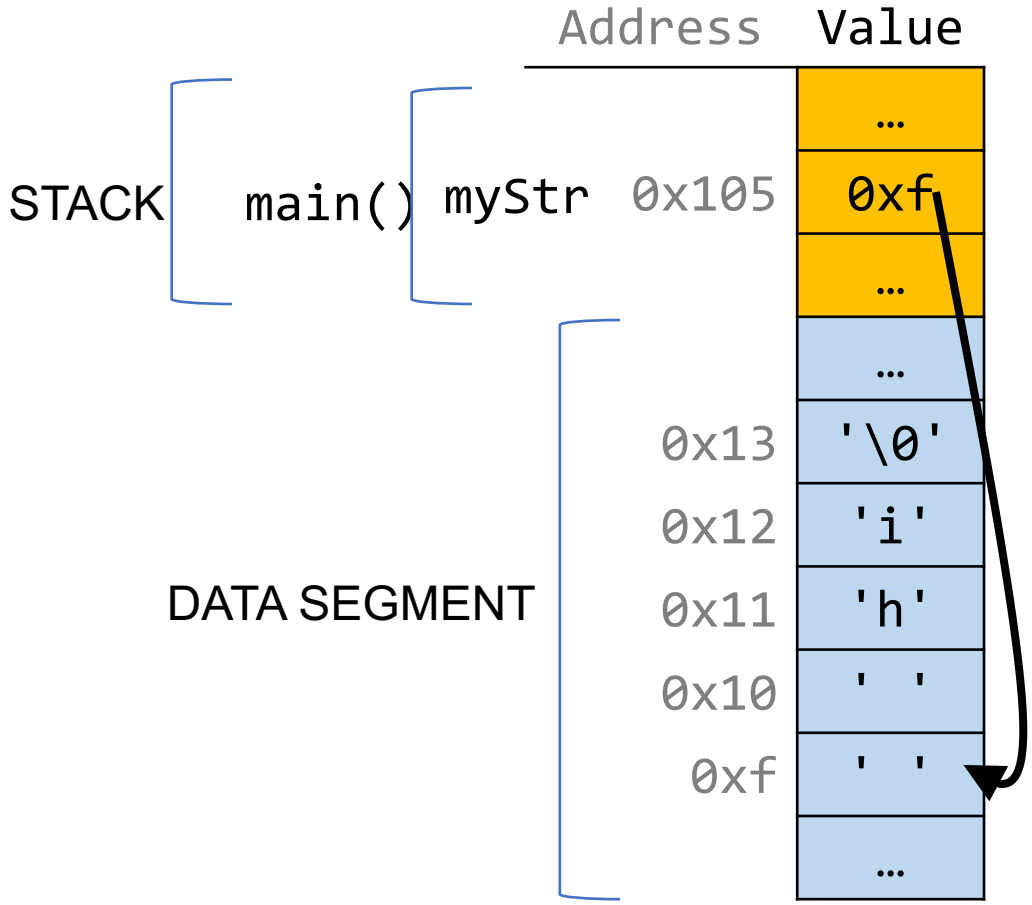
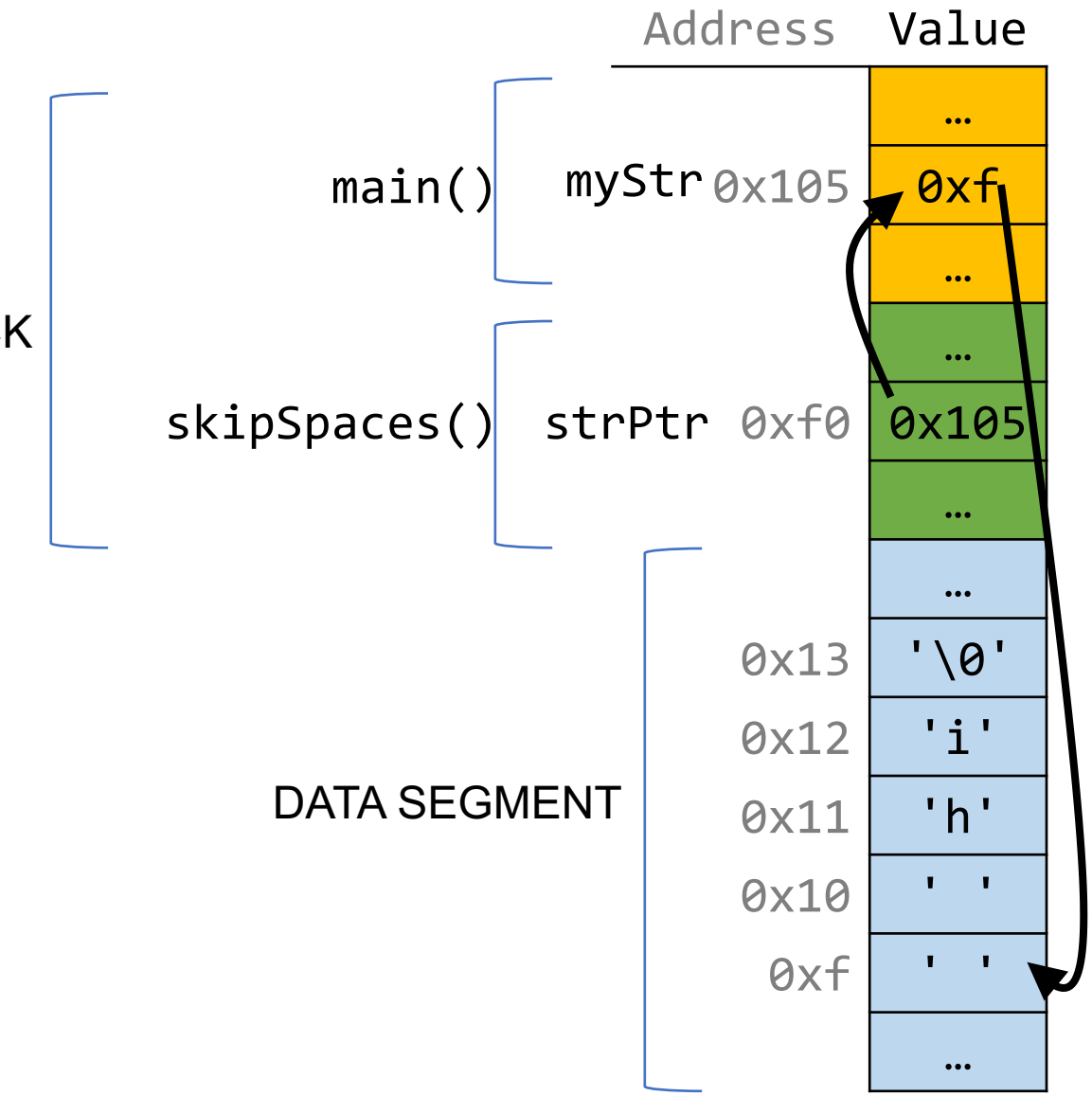
```



Pointers to Strings

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

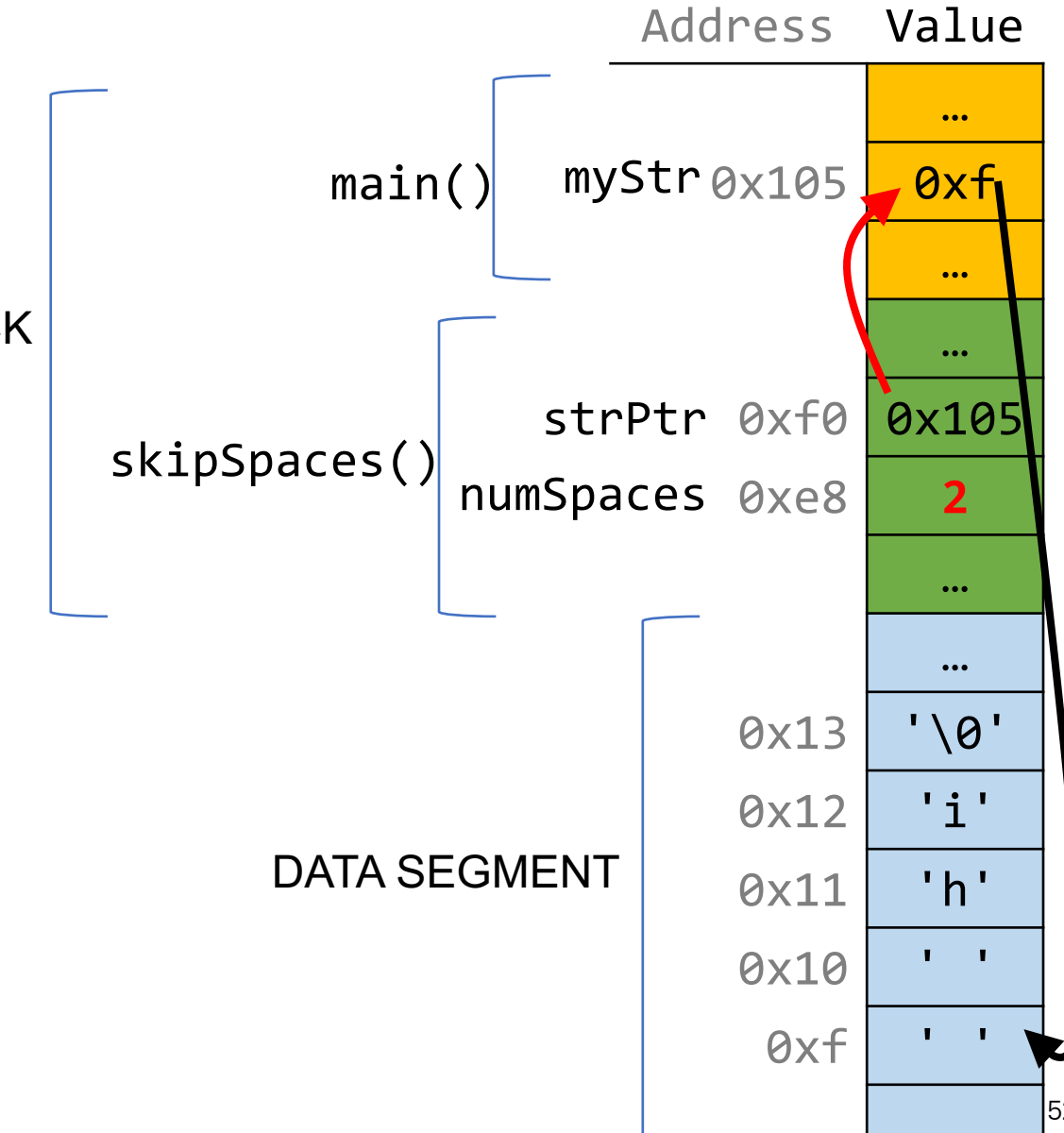
int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



Pointers to Strings

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

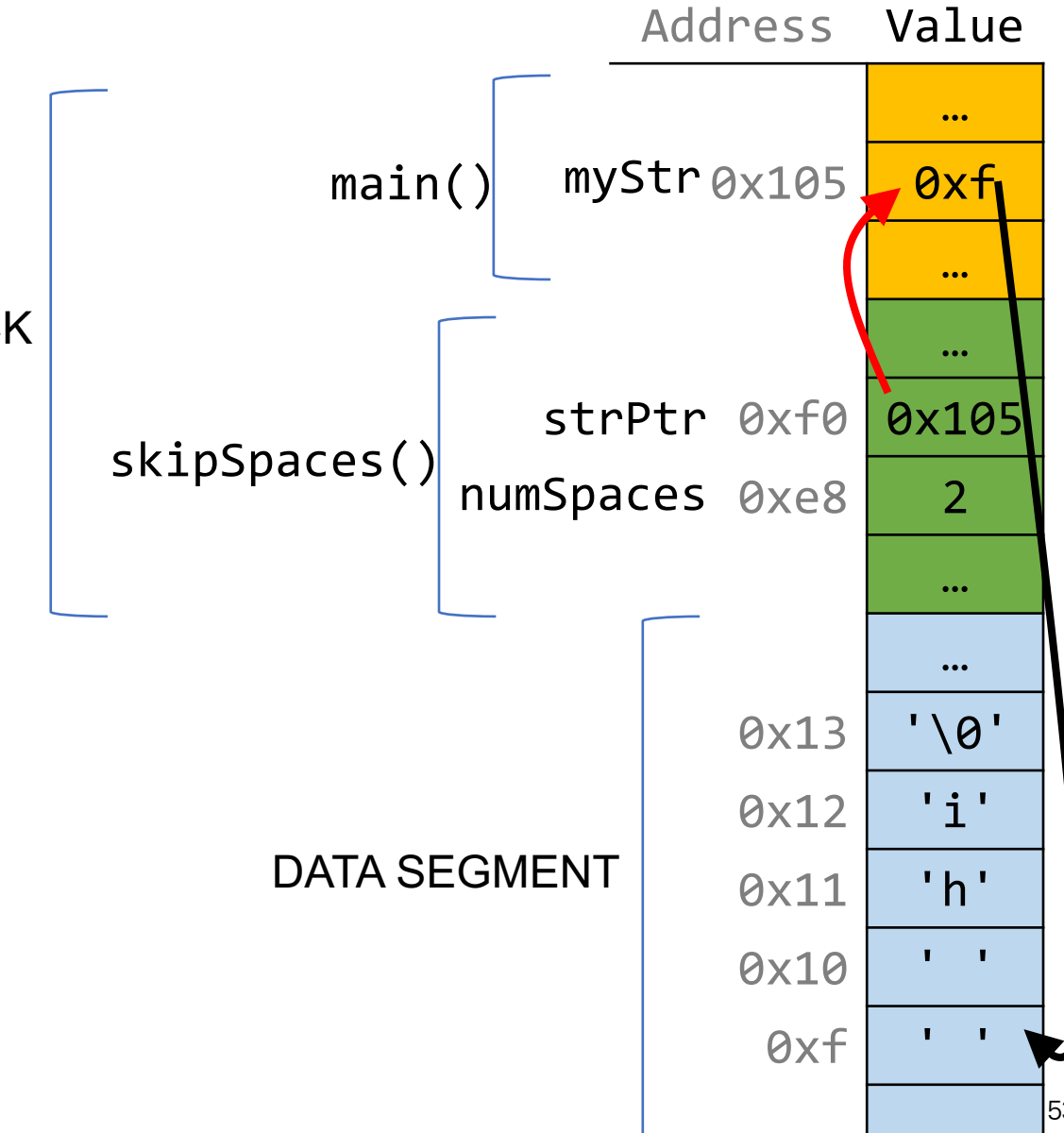
int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);        // hi
    return 0;
}
```



Pointers to Strings

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

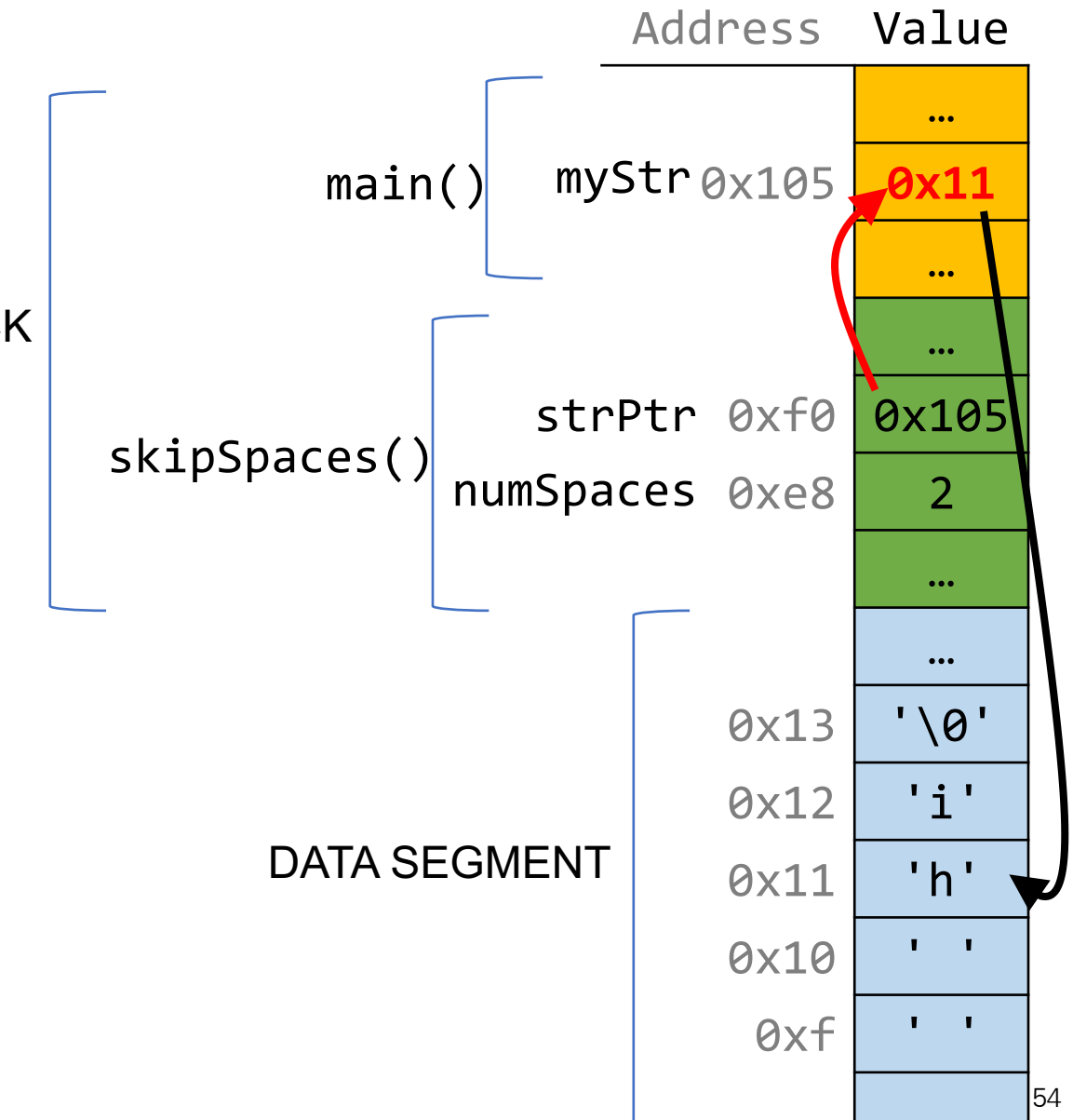
int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);        // hi
    return 0;
}
```



Pointers to Strings

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

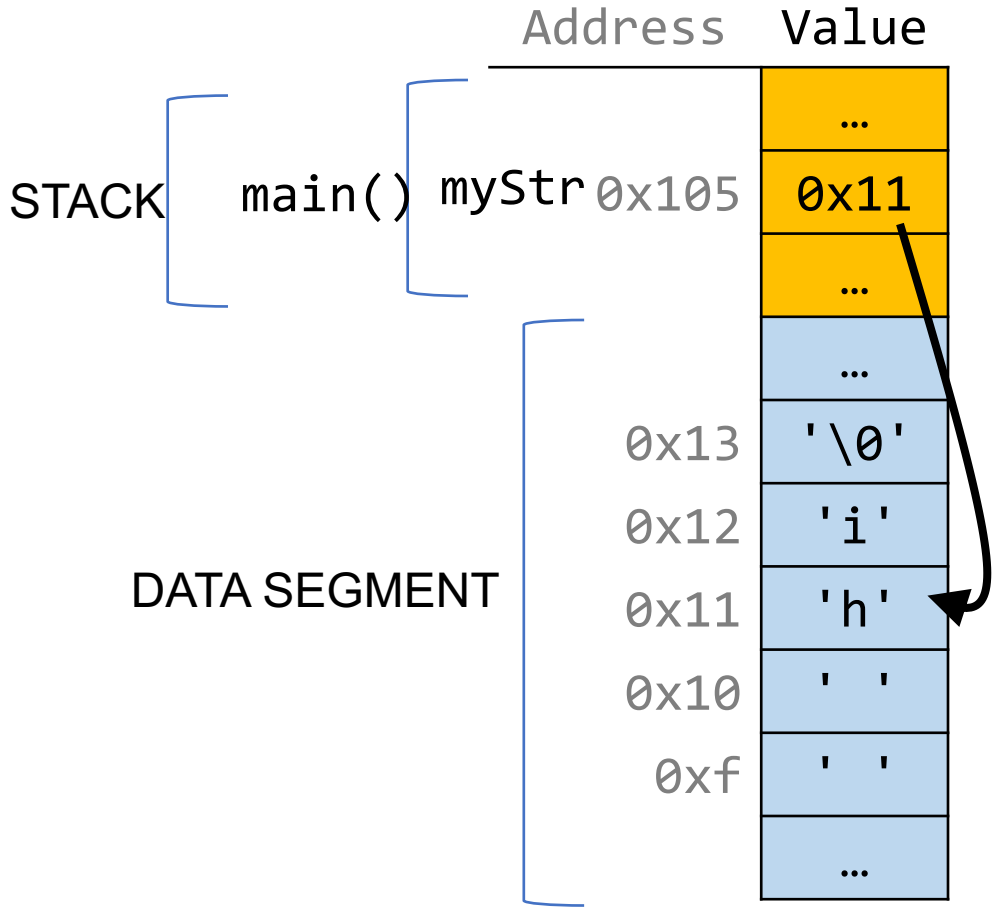
int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



Pointers to Strings

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

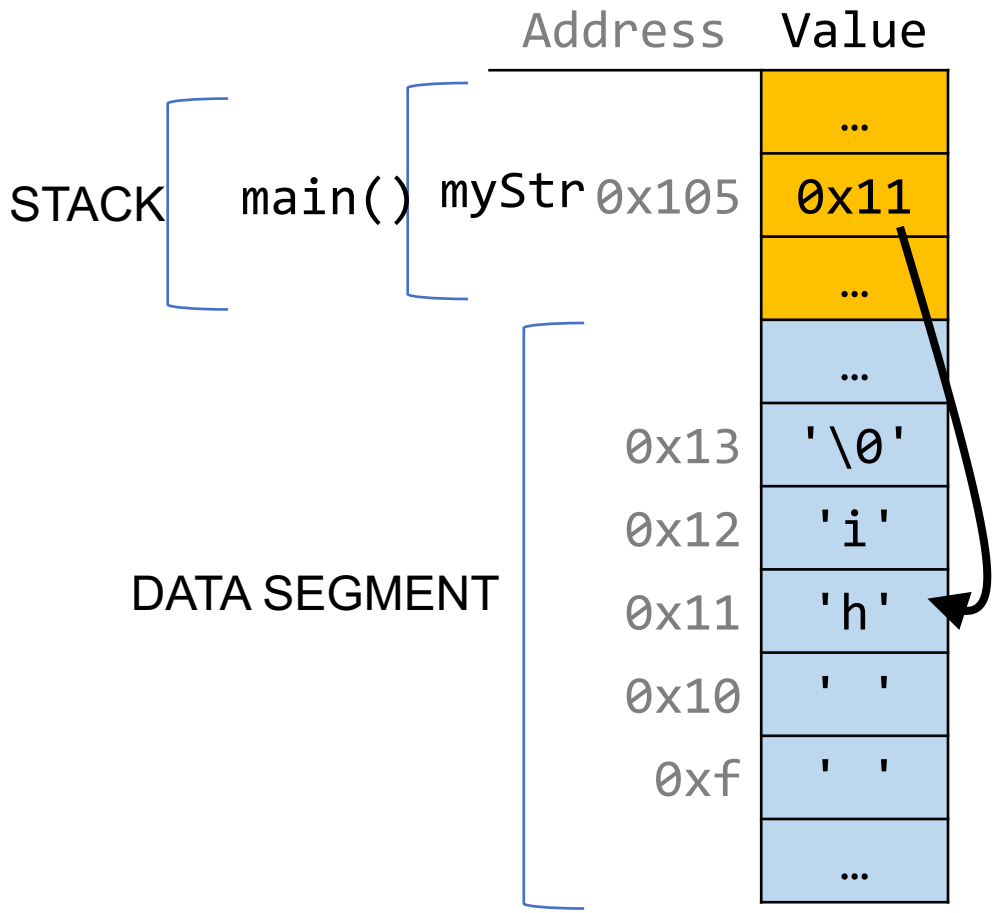
int main(int argc, char *argv[]) {
    char *myStr = "  hi";
    skipSpaces(&myStr);
    printf("%s\n", myStr);       // hi
    return 0;
}
```



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;
}
```

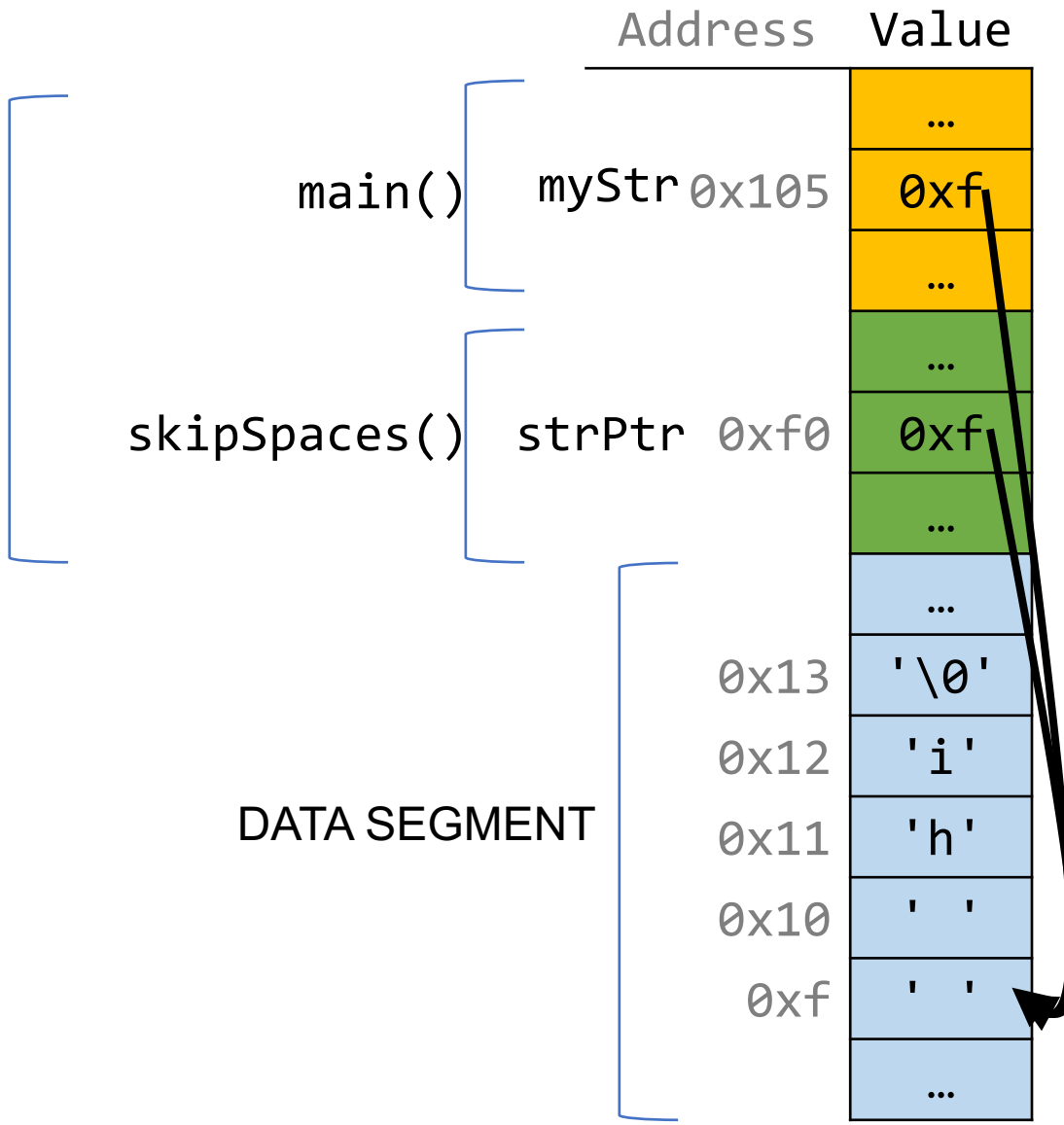


Making Copies

```
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);
    return 0;
}
```

myFunc myFunc
// hi

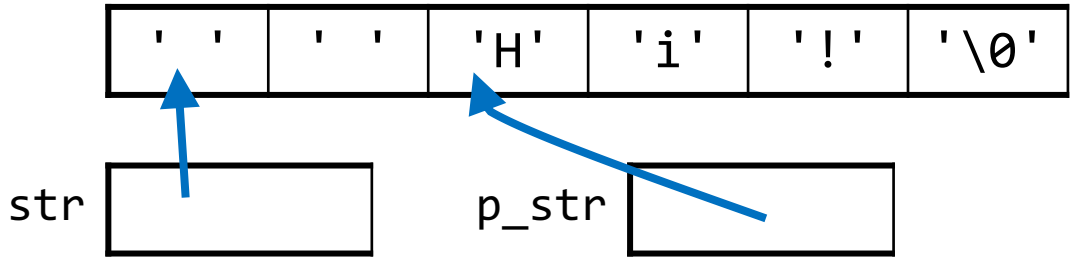


Skip spaces

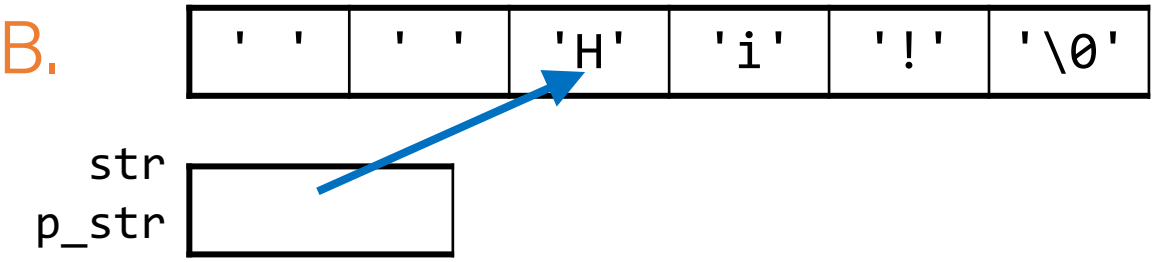
```
1  void skip_spaces(char **p_str) {
2    int num = strspn(*p_str, " ");
3    *p_str = *p_str + num;
4  }
5  int main(int argc, char *argv[]){
6    char *str = "  Hi!";
7    skip_spaces(&str);
8    printf("%s", str); // "Hi!"
9    return 0;
10 }
```

What diagram most accurately depicts program state at Line 4 (before `skip_spaces` returns to `main`)?

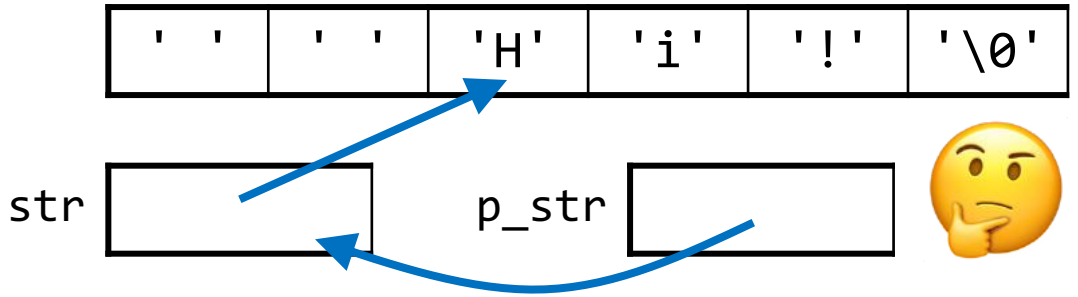
A.



B.



C.



Skip spaces

```
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2    int num = strspn(*p_str, " ");
3    *p_str = *p_str + num;
4  }
5  int main(int argc, char *argv[]){
6    char *str = "  Hi!";
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8    printf("%s", str); // "Hi!"
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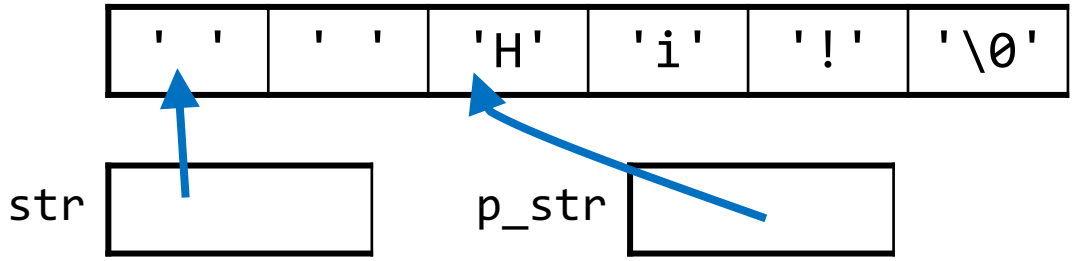
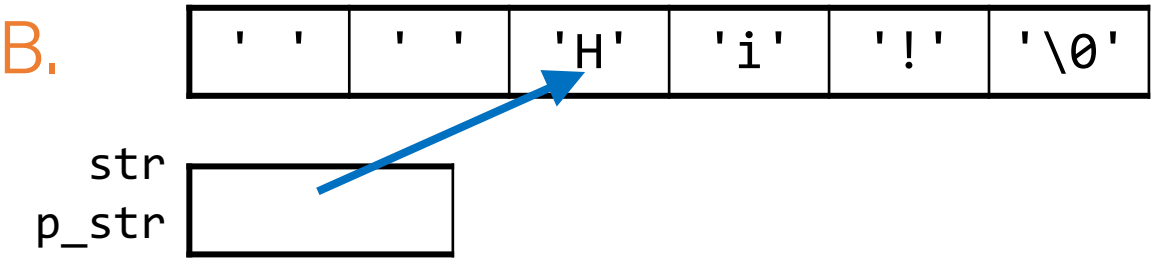
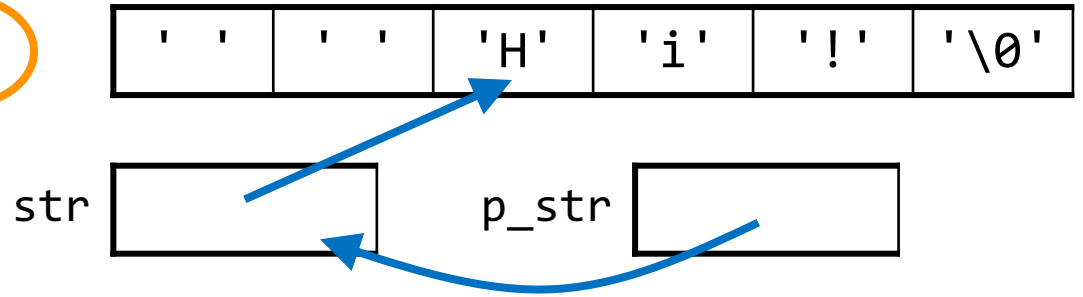


B.



C.



Lecture Plan

- Pointers and Parameters
- Double Pointers
- Arrays in Memory
- Arrays of Pointers
- Pointer Arithmetic

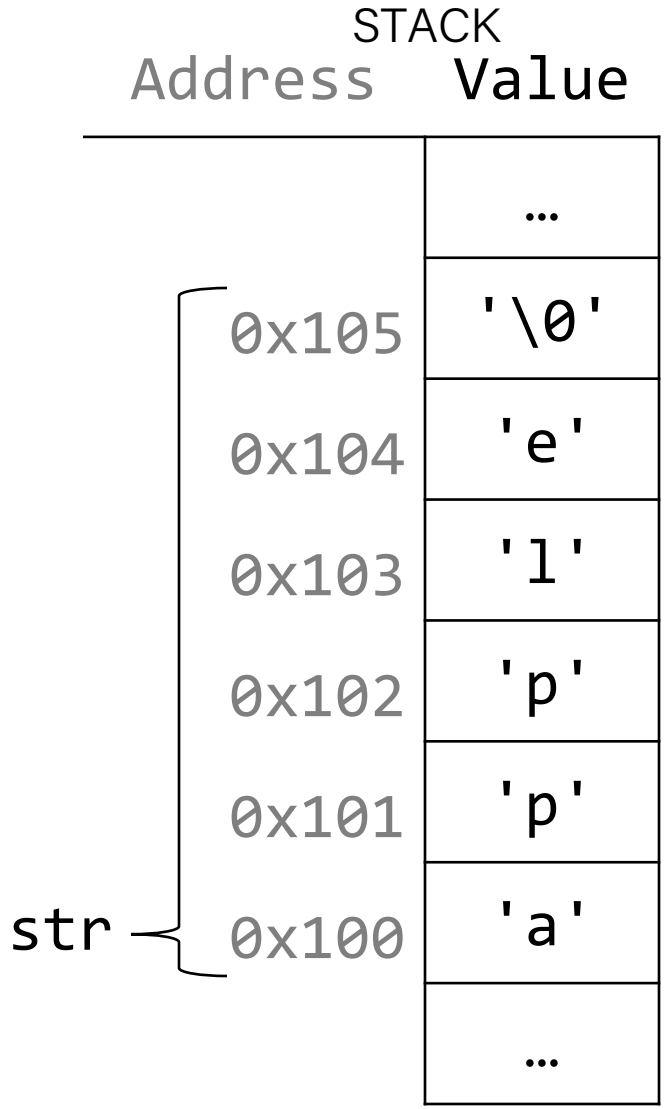
Arrays

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

```
char str[6];
strcpy(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!
```

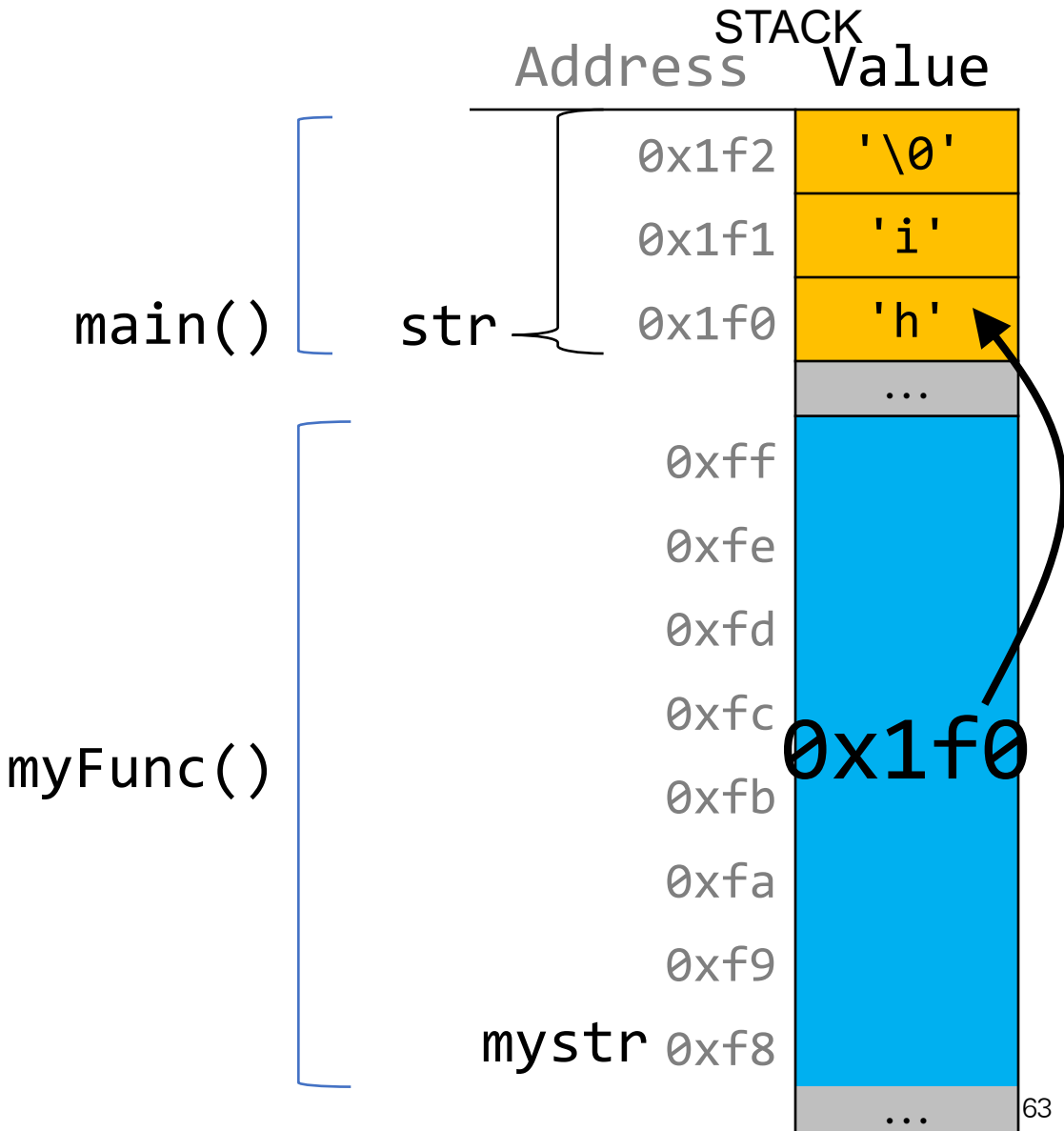
An array's size cannot be changed once you create it; you must create another new array instead.

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[3];
      strcpy(str, "hi");
      myFunc(str);
      ...
}
```

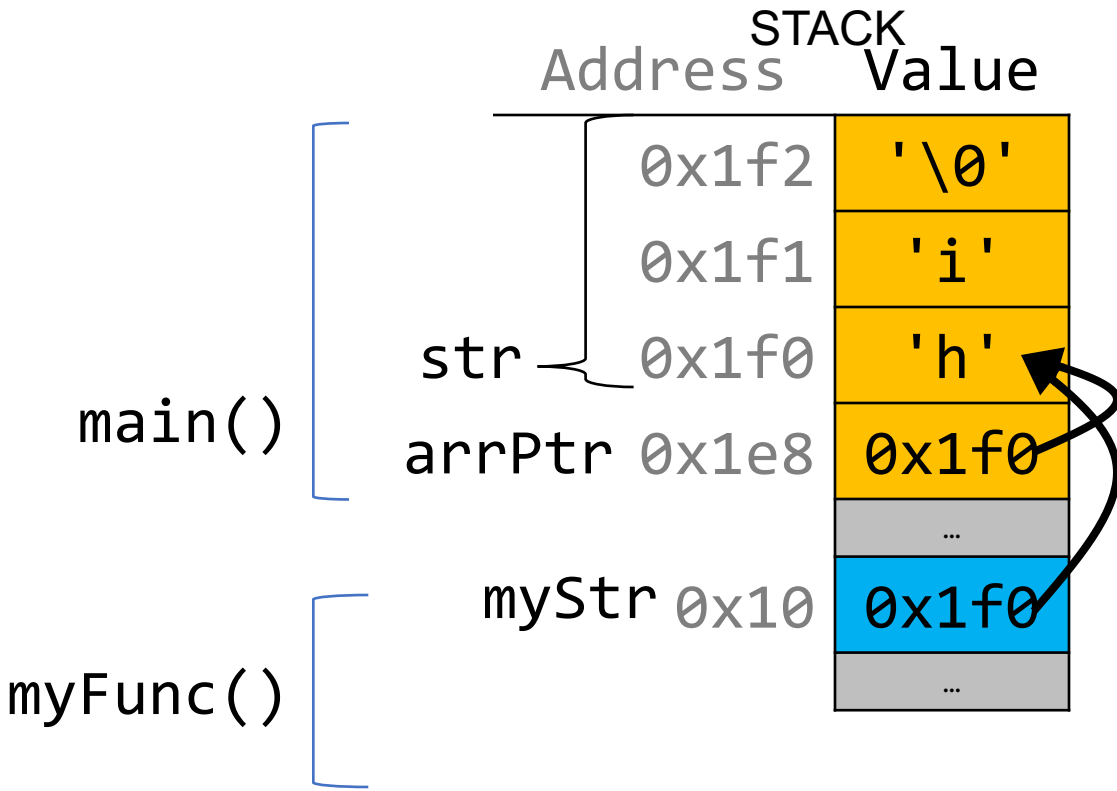


Arrays as Parameters

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[3];
      strcpy(str, "hi");
      // equivalent
      char *arrPtr = str;
      myFunc(arrPtr);
      ...
}
```

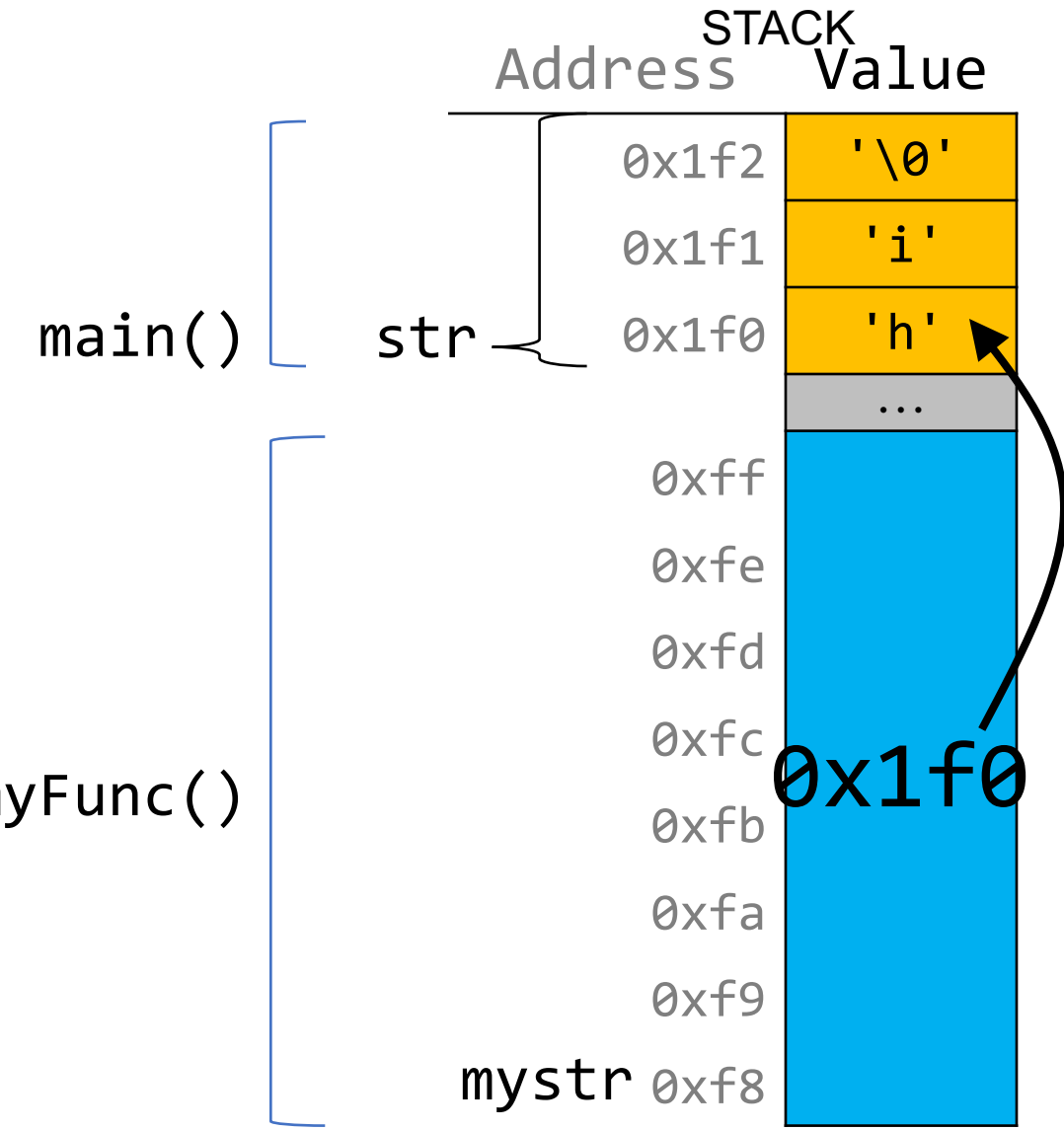


Arrays as Parameters

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[3];
      strcpy(str, "hi");
      int size = sizeof(str);   // 3
      myFunc(str);
      ...
}
```

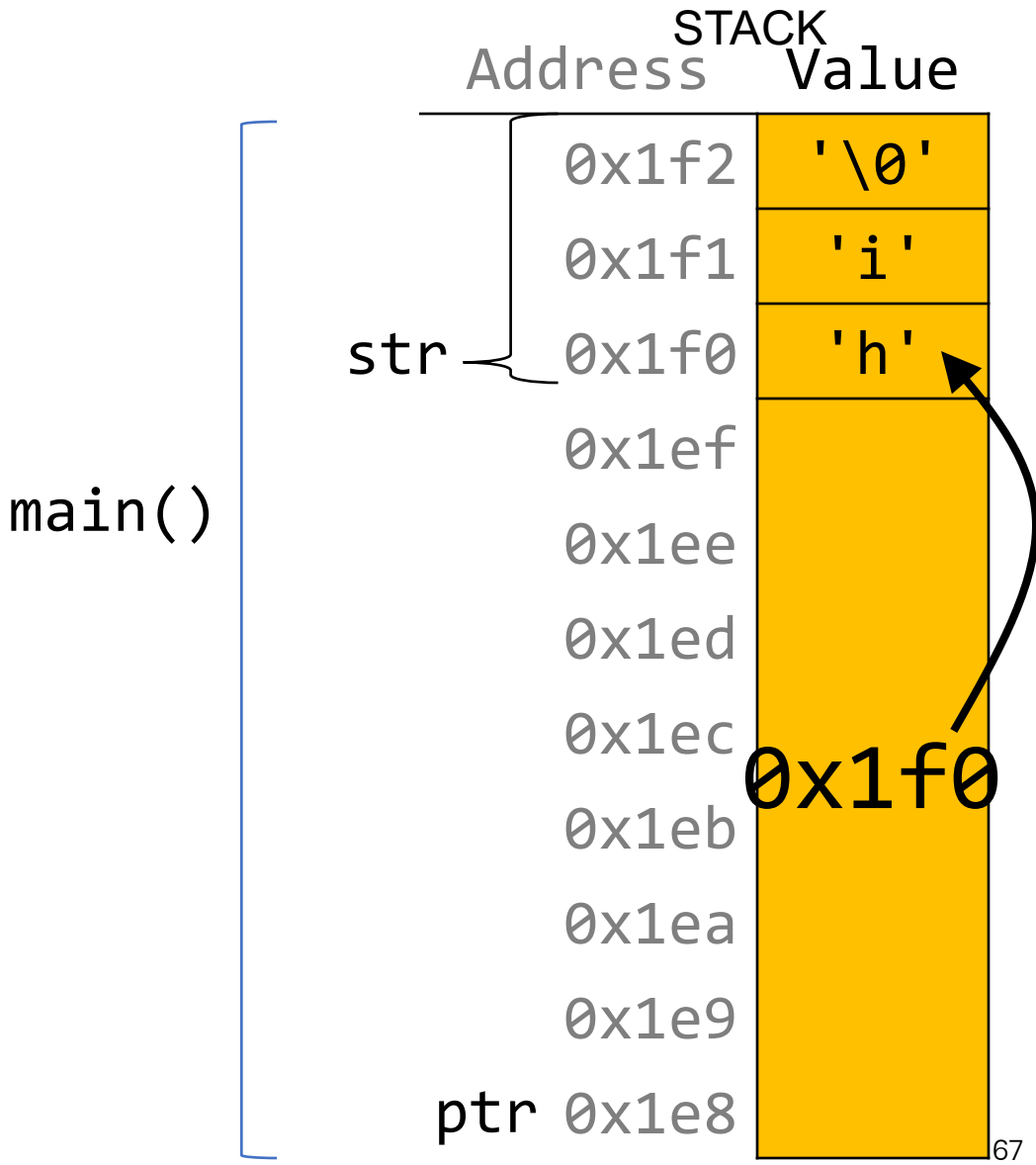


`sizeof` returns the size of an array, or 8 for a pointer. Therefore, when we pass an array as a parameter, we can no longer use **`sizeof`** to get its full size.

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[3];
      strcpy(str, "hi");
      char *ptr = str;
      ...
}
```



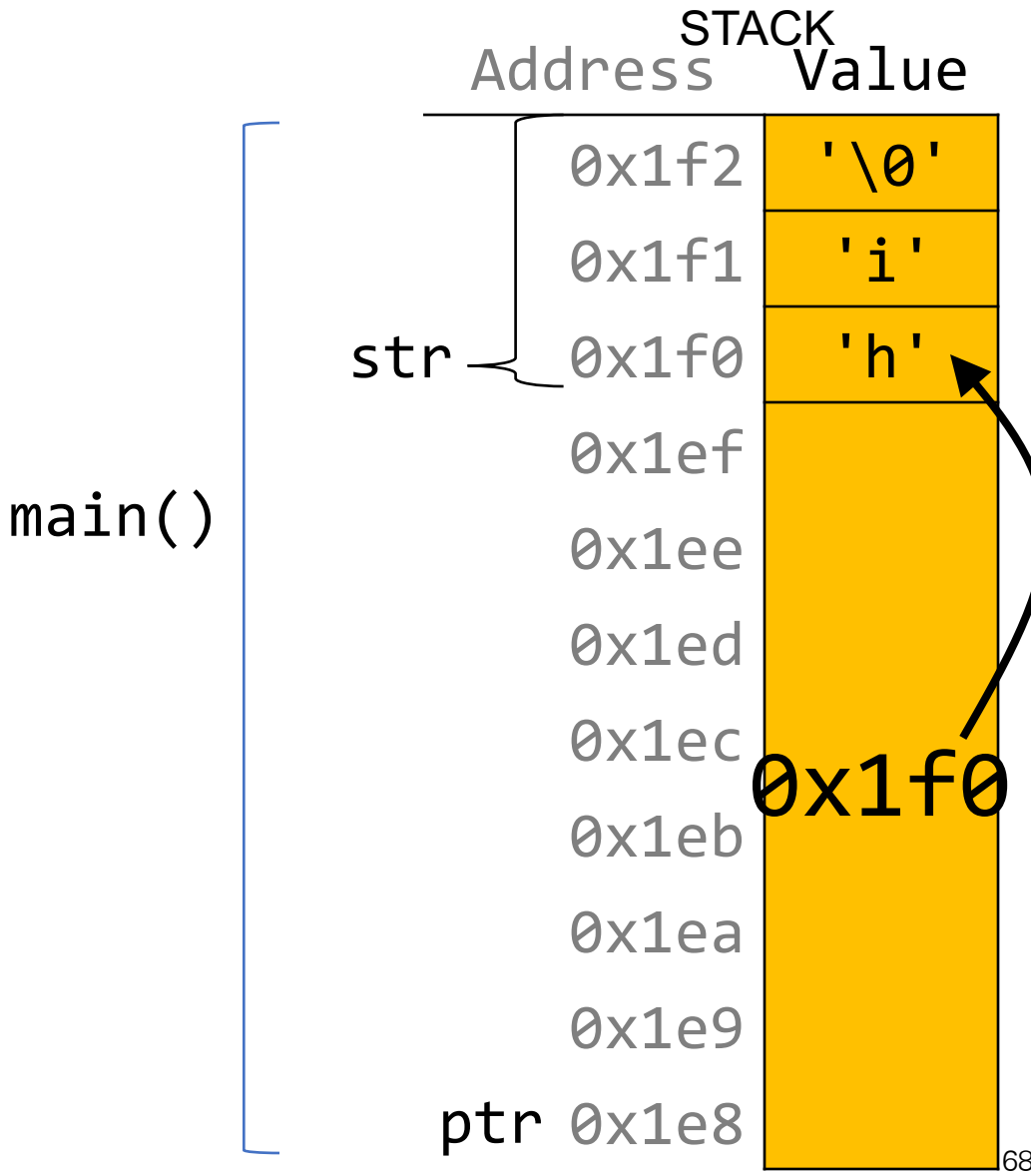
Arrays and Pointers

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[3];
      strcpy(str, "hi");
      char *ptr = str;

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

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



Lecture Plan

- Pointers and Parameters
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Arrays Of Pointers

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

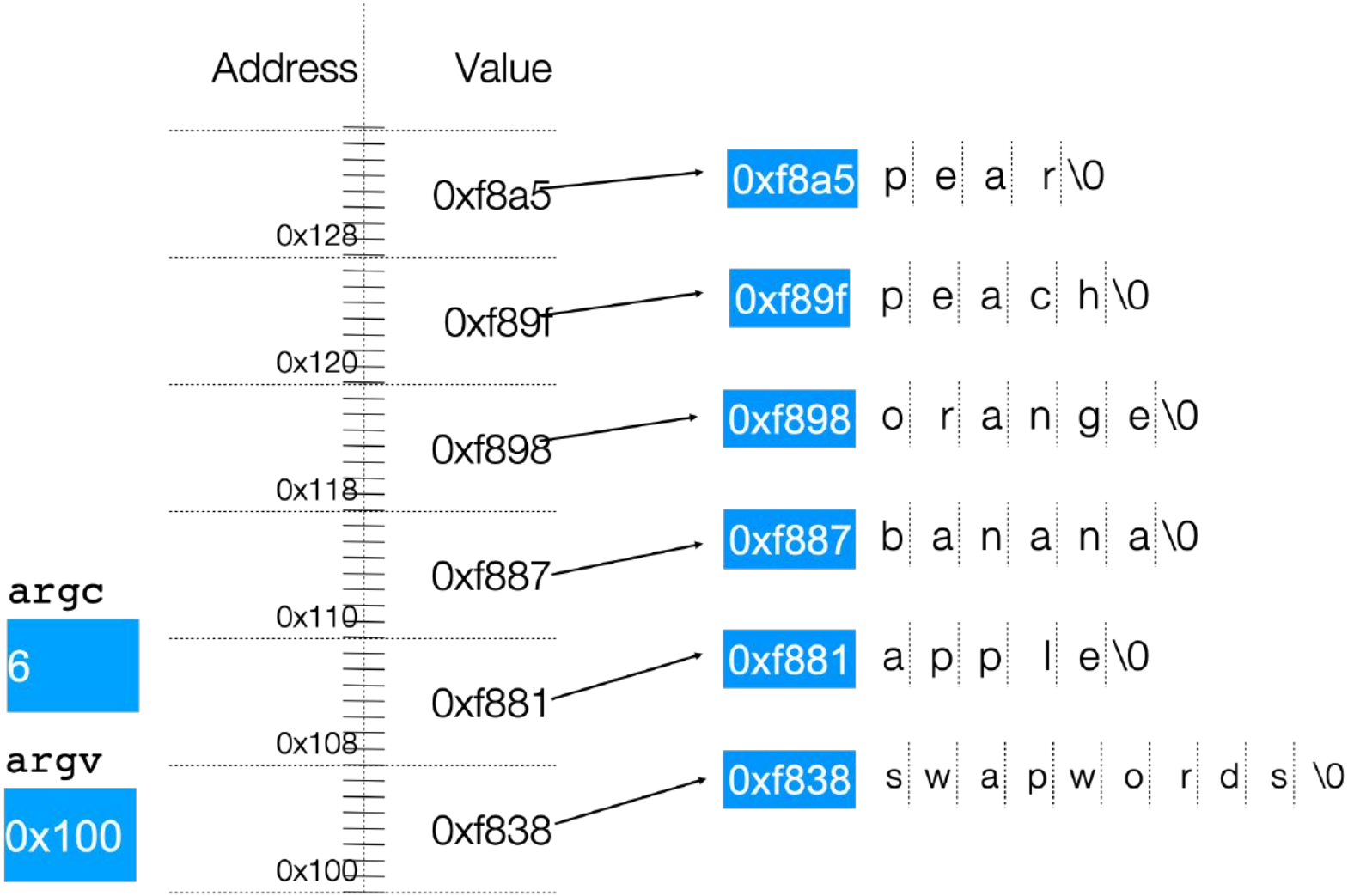
```
char *stringArray[5];  // space to store 5 char *s
```

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

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

Arrays Of Pointers

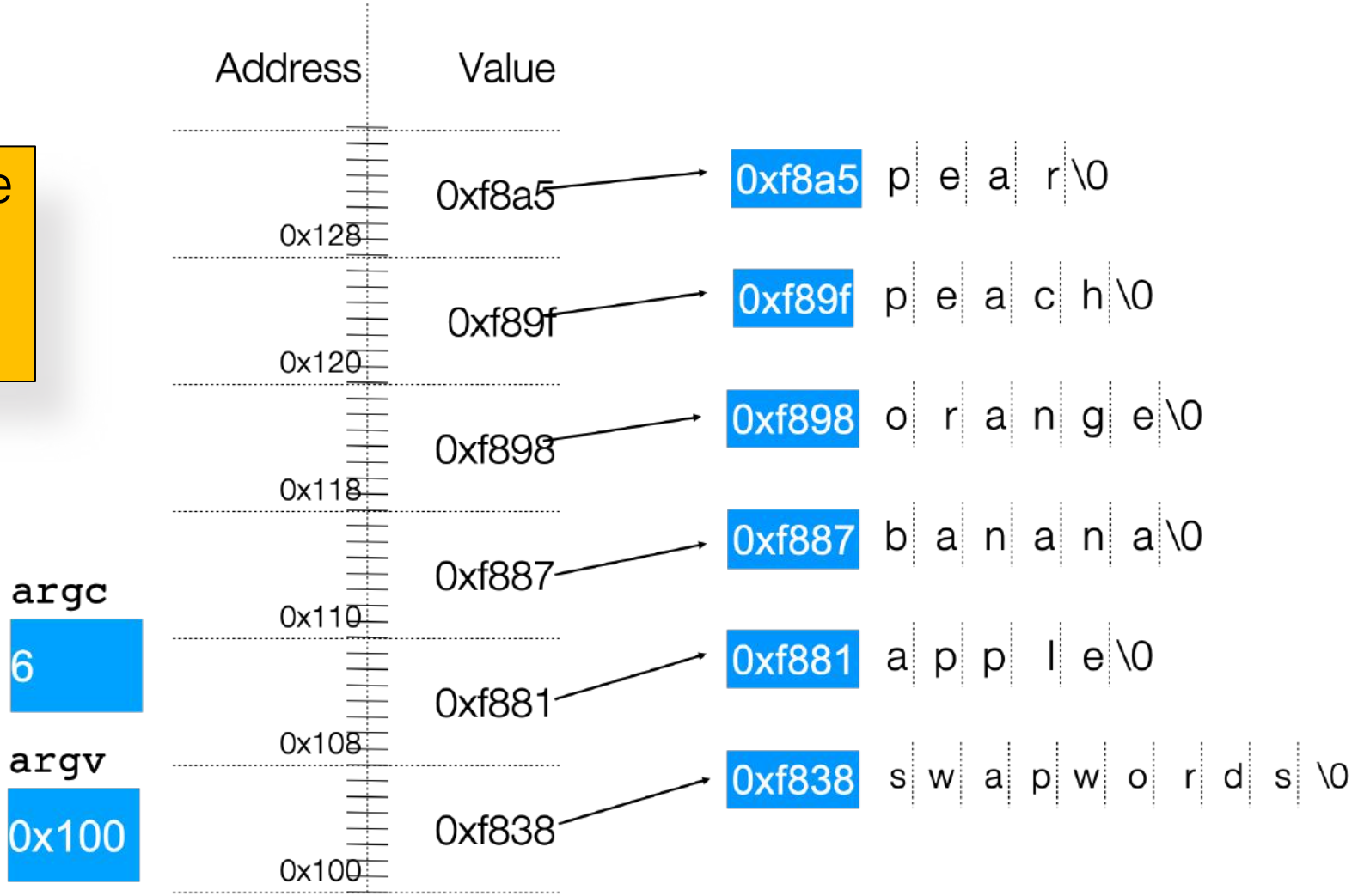
```
./swapwords apple banana orange peach pear
```



Arrays Of Pointers

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

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



Lecture Plan

- Pointers and Parameters
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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

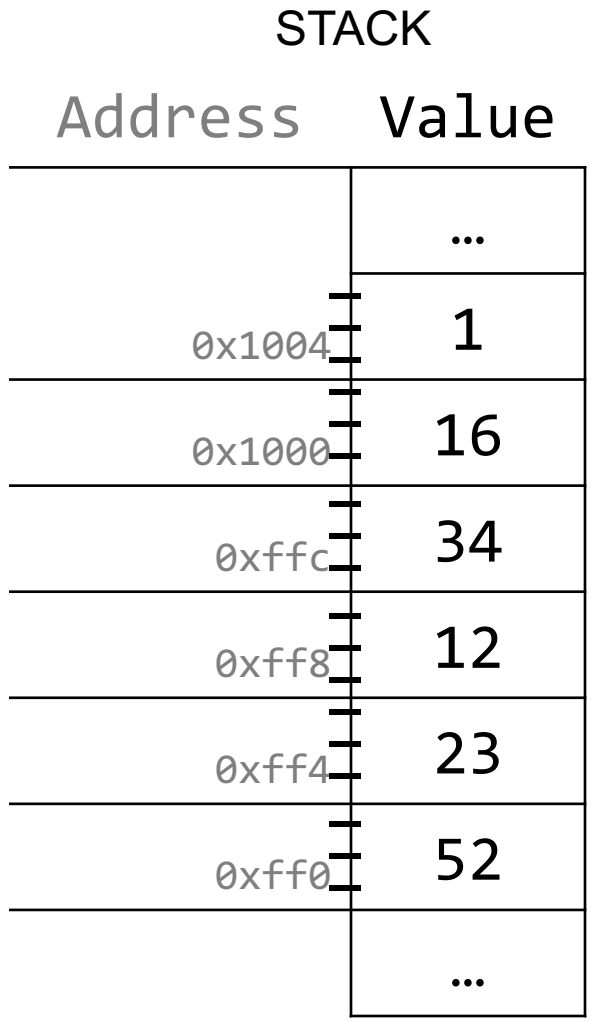
Address	Value
	…
0xff5	'\0'
0xff4	'e'
0xff3	'l'
0xff2	'p'
0xff1	'p'
0xff0	'a'
	…

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

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'
```

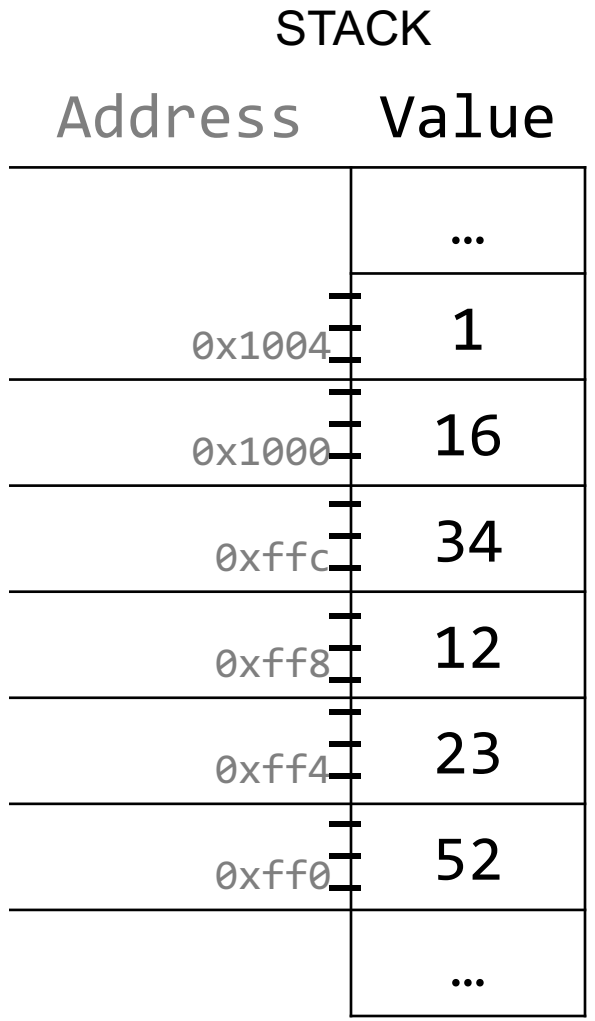
DATA SEGMENT

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
```



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

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[6];
strcpy(str, "COMP201");

// 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.

Pointer arithmetic

Array indexing is “syntactic sugar” for pointer arithmetic:

```
ptr + i          ⇔        &ptr[i]
*(ptr + i)       ⇔        ptr[i]
```

⚠️ Pointer arithmetic **does not work in bytes**; it works on the type it points to. On `int*` addresses scale by `sizeof(int)`, on `char*` scale by `sizeof(char)`.

- This means too-large/negative subscripts will compile ☺

```
arr[99]                    arr[-1]
```

- You can use either syntax on either pointer or array.

Recap

- Pointers and Parameters
- Double Pointers
- Arrays in Memory
- Arrays of Pointers
- Pointer Arithmetic

Next Time: pointer arithmetic, dynamically allocated memory