CS107, Lecture 6

More Pointers and Arrays

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

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

Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

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.

Memory

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

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

Memory

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

Address	Value
	…
261	'\0'
260	'e'
259	'l'
258	'p'
257	'p'
256	'a'
	…

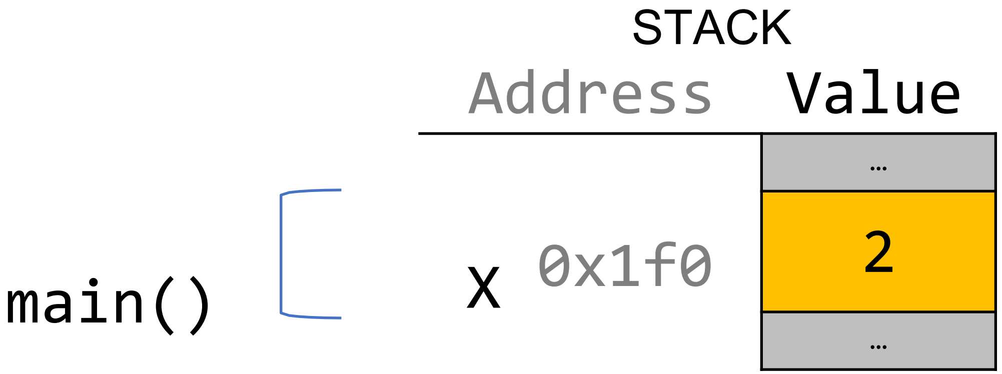
Pointers

```c
int x = 2;

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

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

Pointers

A pointer is a variable that stores a memory address.

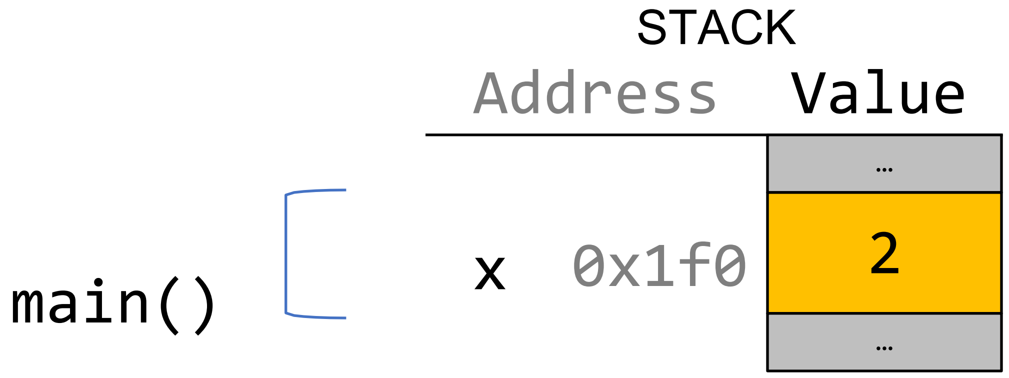
```
void myFunc(int *intPtr) {
      *intPtr = 3;
}

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



Pointers

<u>A pointer is a variable that stores a memory address.</u>

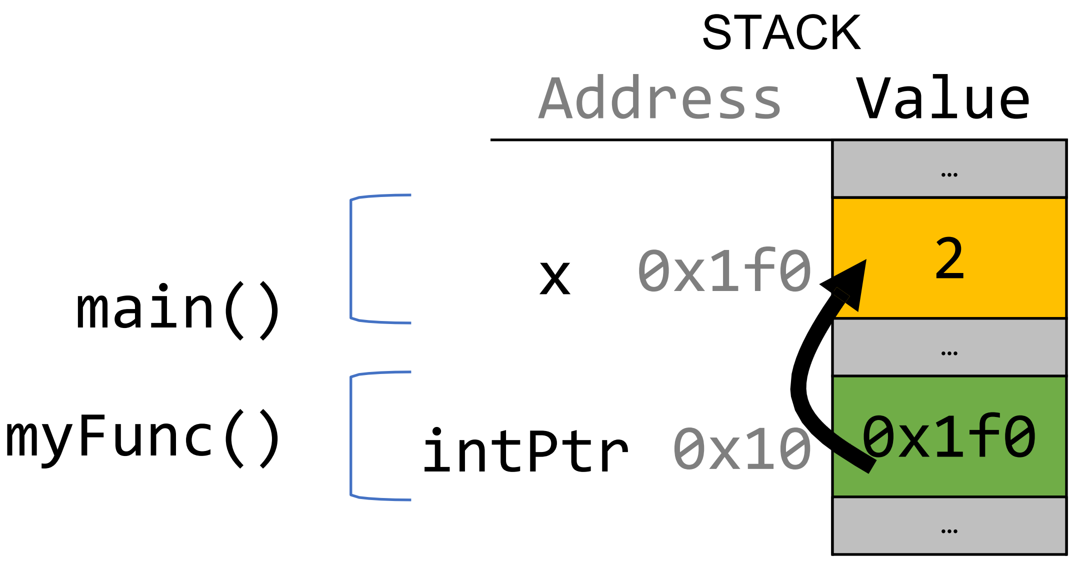
```
void myFunc(int *intPtr) {
      *intPtr = 3;
}

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



Pointers

A pointer is a variable that stores a memory address.

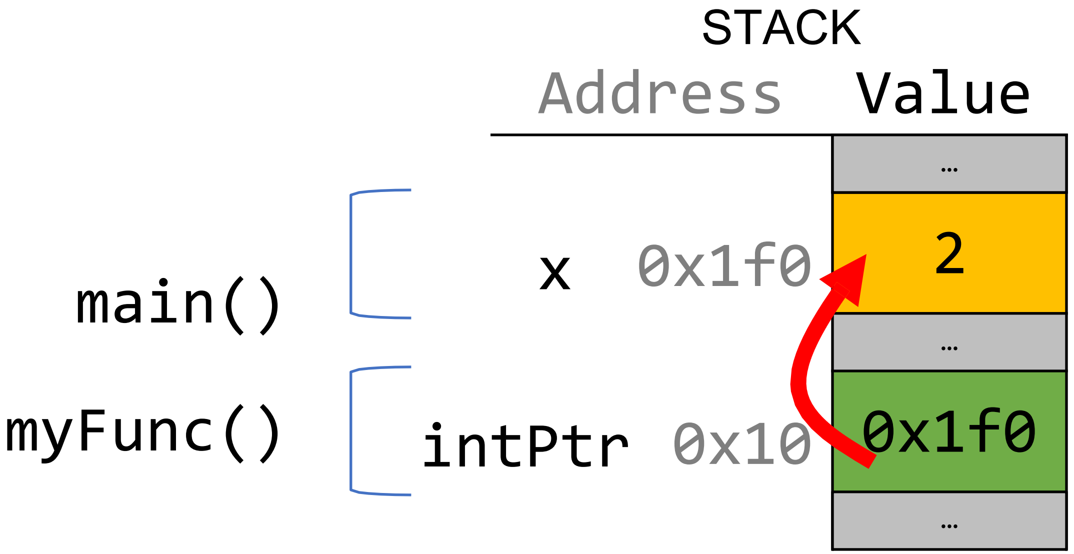
```
void myFunc(int *intPtr) {
	*intPtr = 3;
}

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



Pointers

<u>A pointer is a variable that stores a memory address.</u>

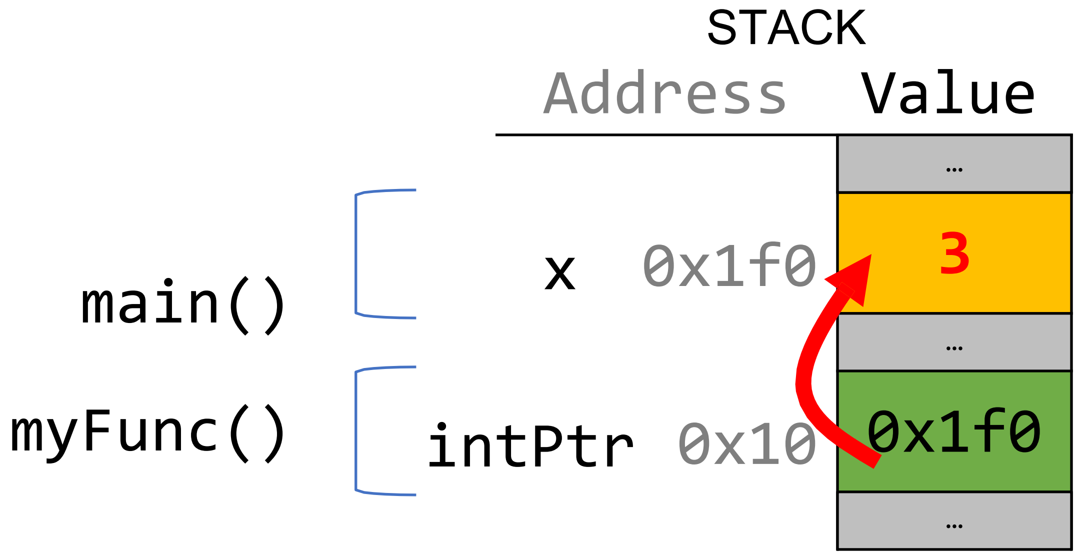
```
void myFunc(int *intPtr) {
      *intPtr = 3;
}

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



Pointers

<u>A pointer is a variable that stores a memory address.</u>

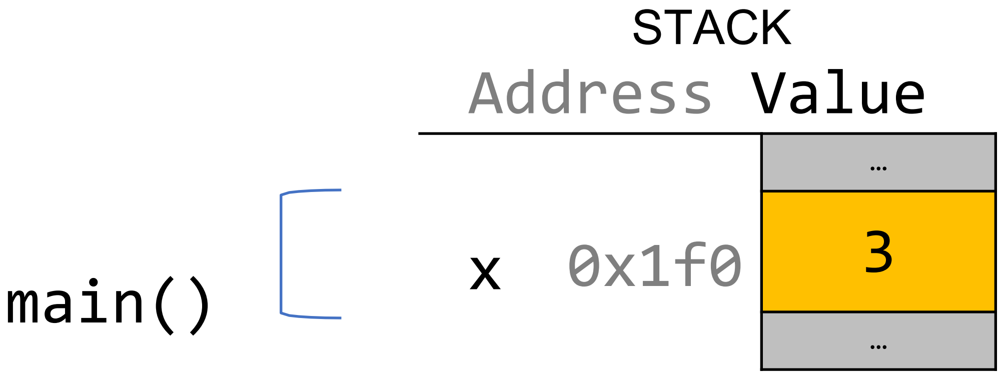
```
void myFunc(int *intPtr) {
      *intPtr = 3;
}

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



Pointers

<u>A pointer is a variable that stores a memory address.</u>

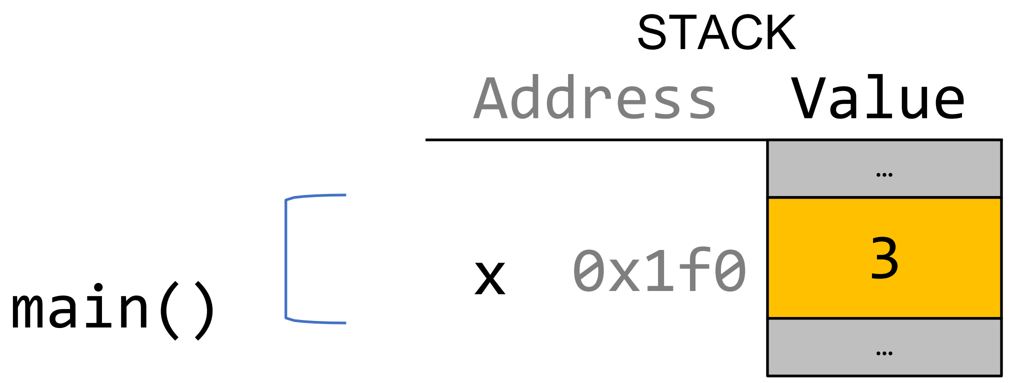
```
void myFunc(int *intPtr) {
     *intPtr = 3;
}

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



Pointers

A pointer is 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.
- If you are modifying a specific instance of some value, pass the *location* of what you would like to modify and dereference that location to access what's there.

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.

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
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 num1 + num2;
}

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

C Parameters

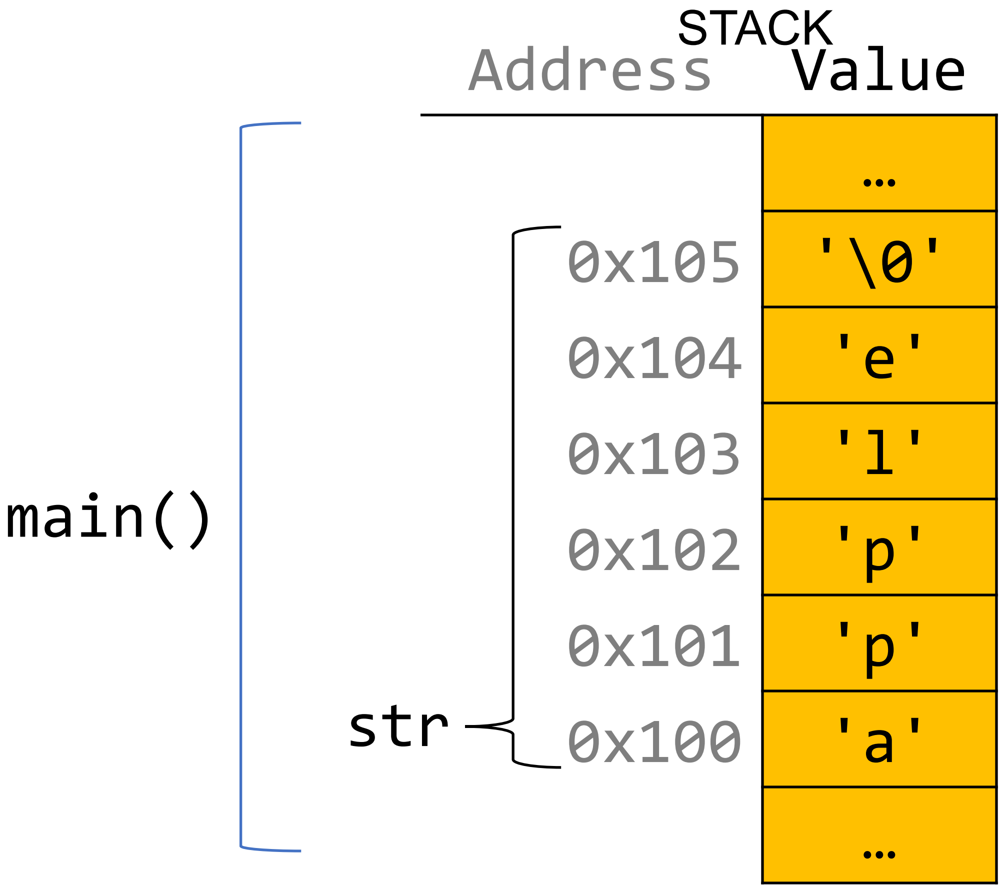
If you are modifying a specific instance of some value, pass the *location* of what you would like to modify.

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.

char[]

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

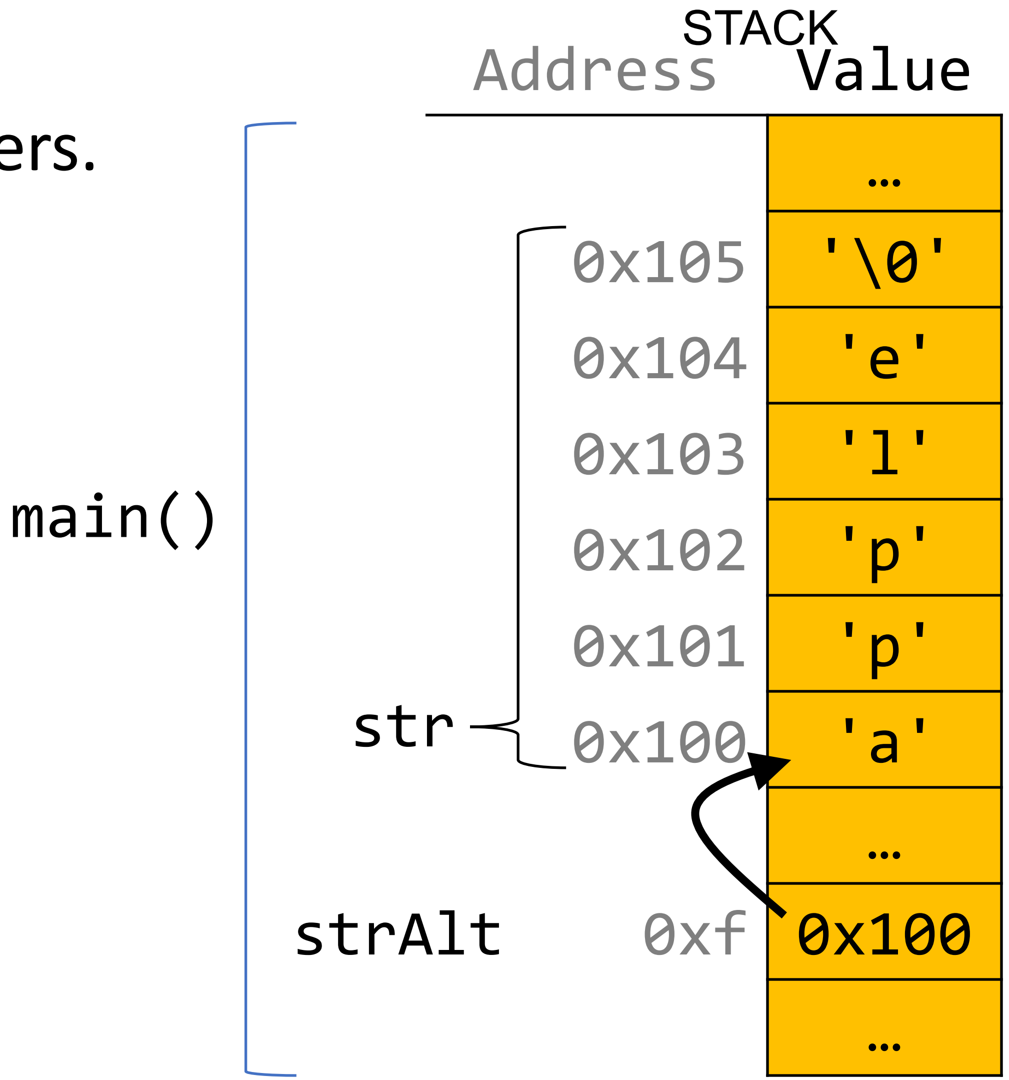
```
int main(int argc, char *argv[]) {
    char str[6];
    strcpy(str, "apple");
    ...
```



char *

When we declare a **char ***, we allocate space on the stack to store an address, not actual characters. But we can still generally use **char *** the same as **char[]**.

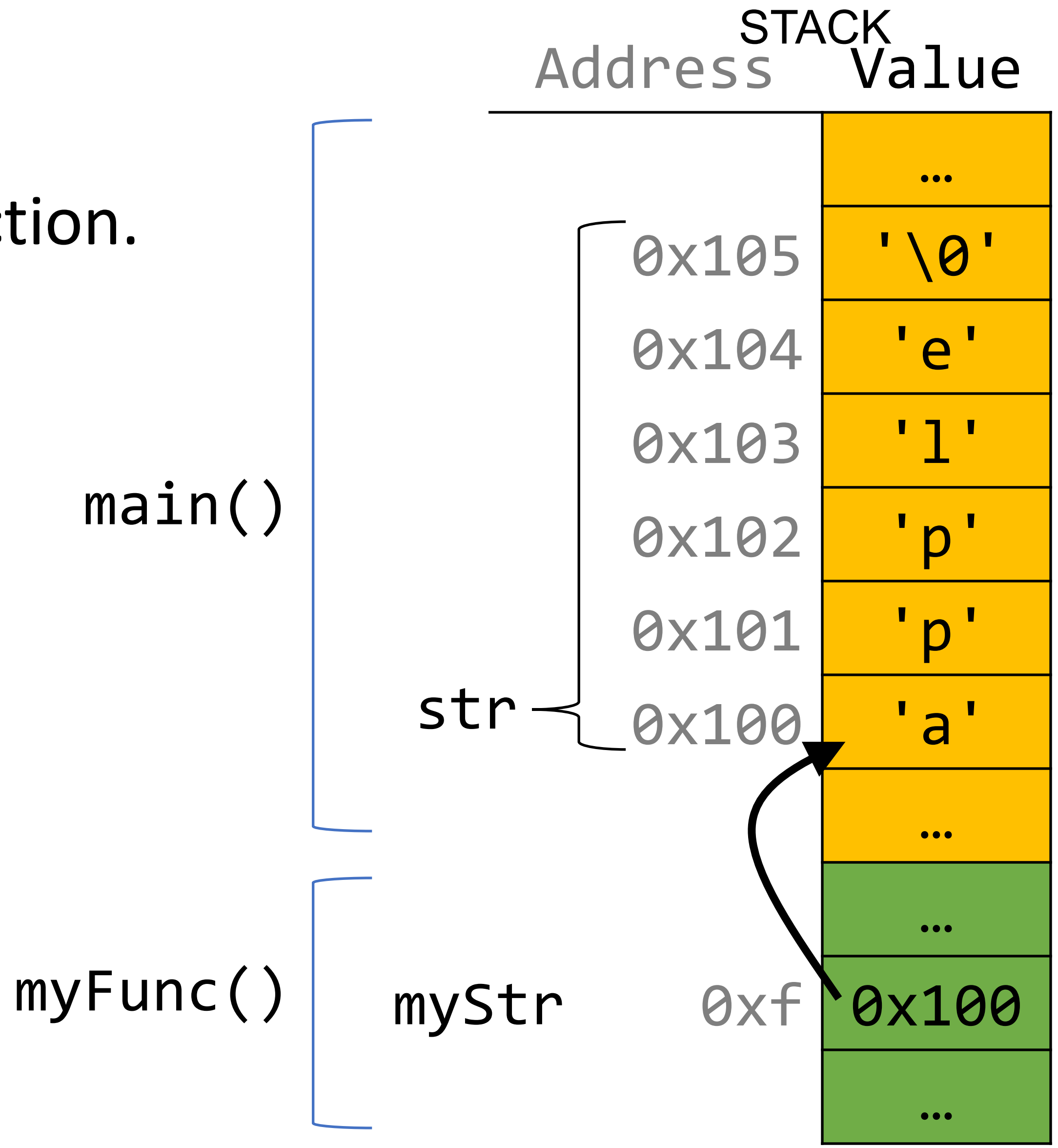
```
int main(int argc, char *argv[]) {
    char str[6];
    strcpy(str, "apple");
    char *strAlt = str;
    ...
```



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.

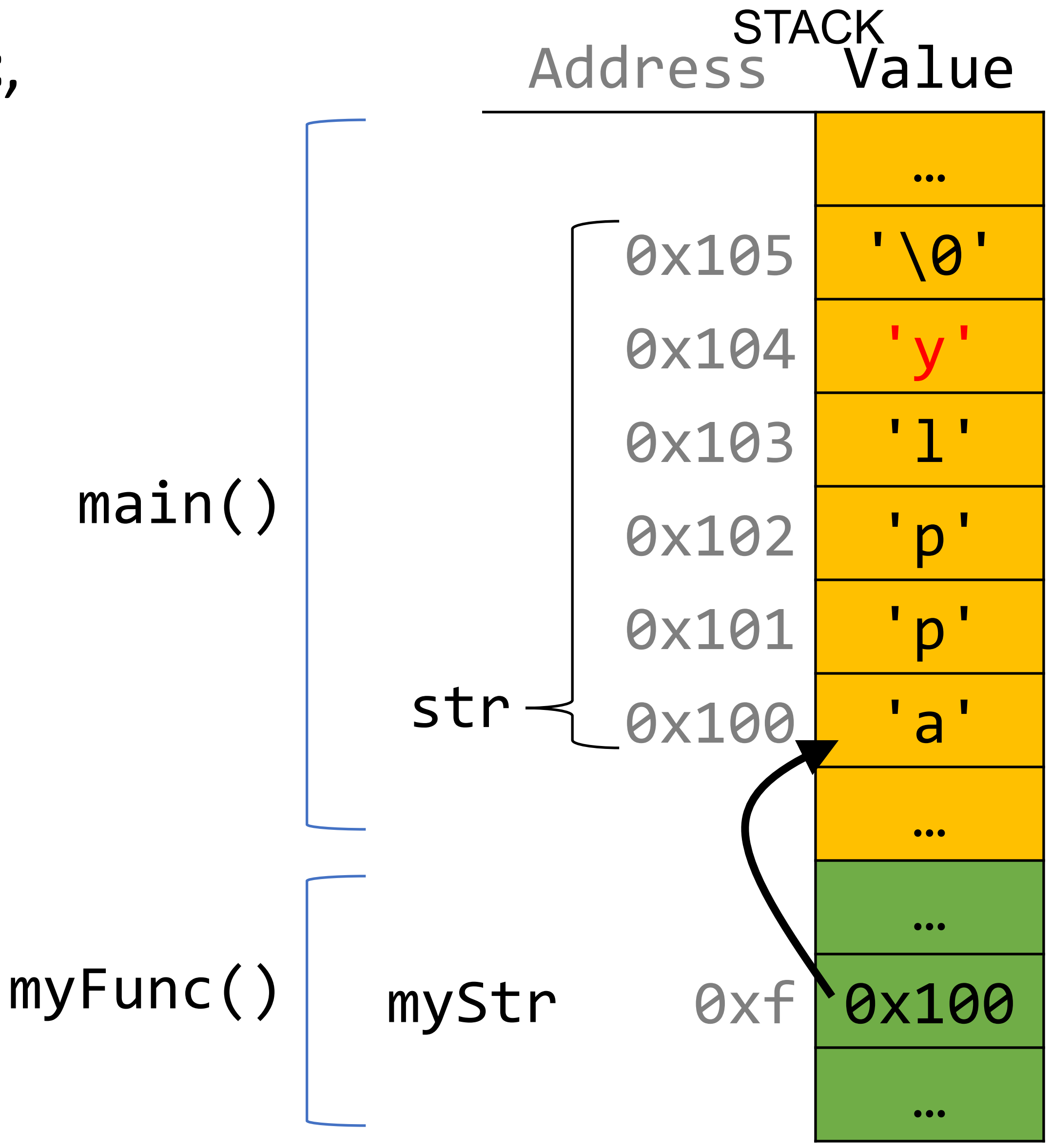
```
void myFunc(char *myStr) {
      ...
}

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



Strings as Parameters

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
	...
}
```



char *

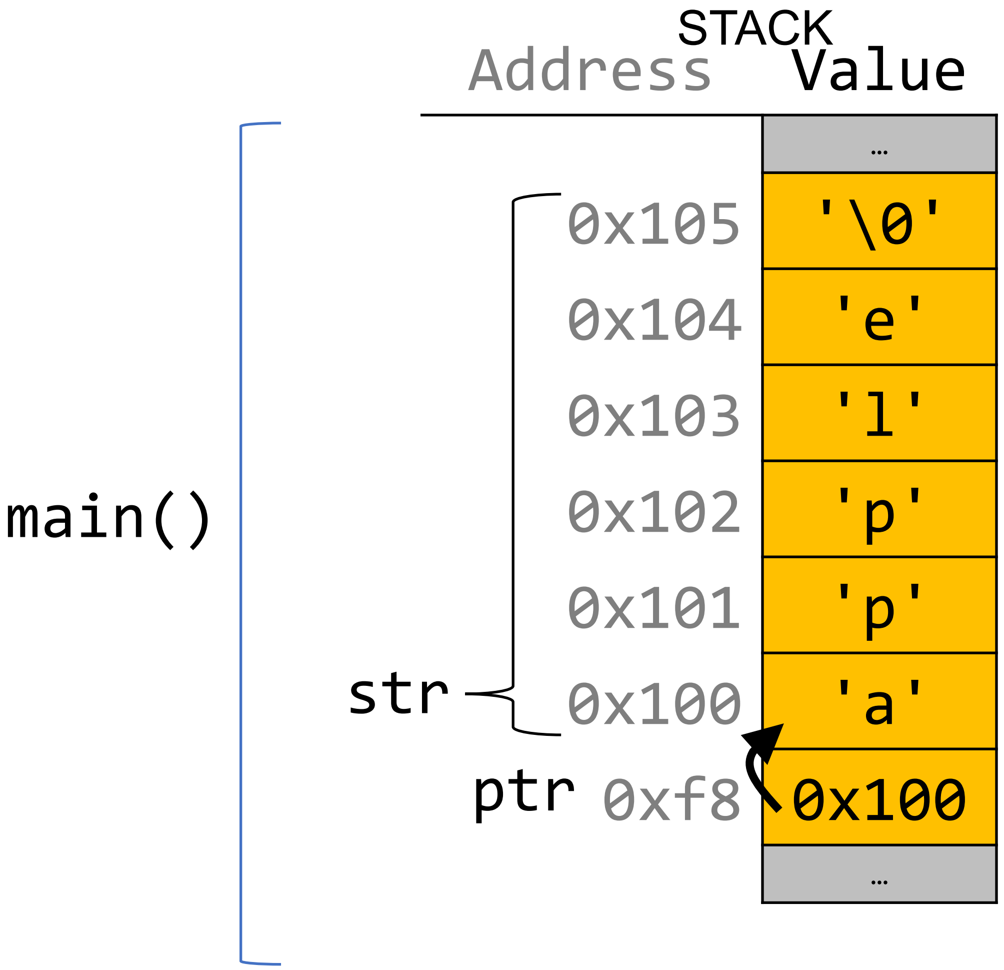
A **char *** variable refers to a single character. We can reassign an existing **char *** pointer to be equal to another **char *** pointer.

```
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.

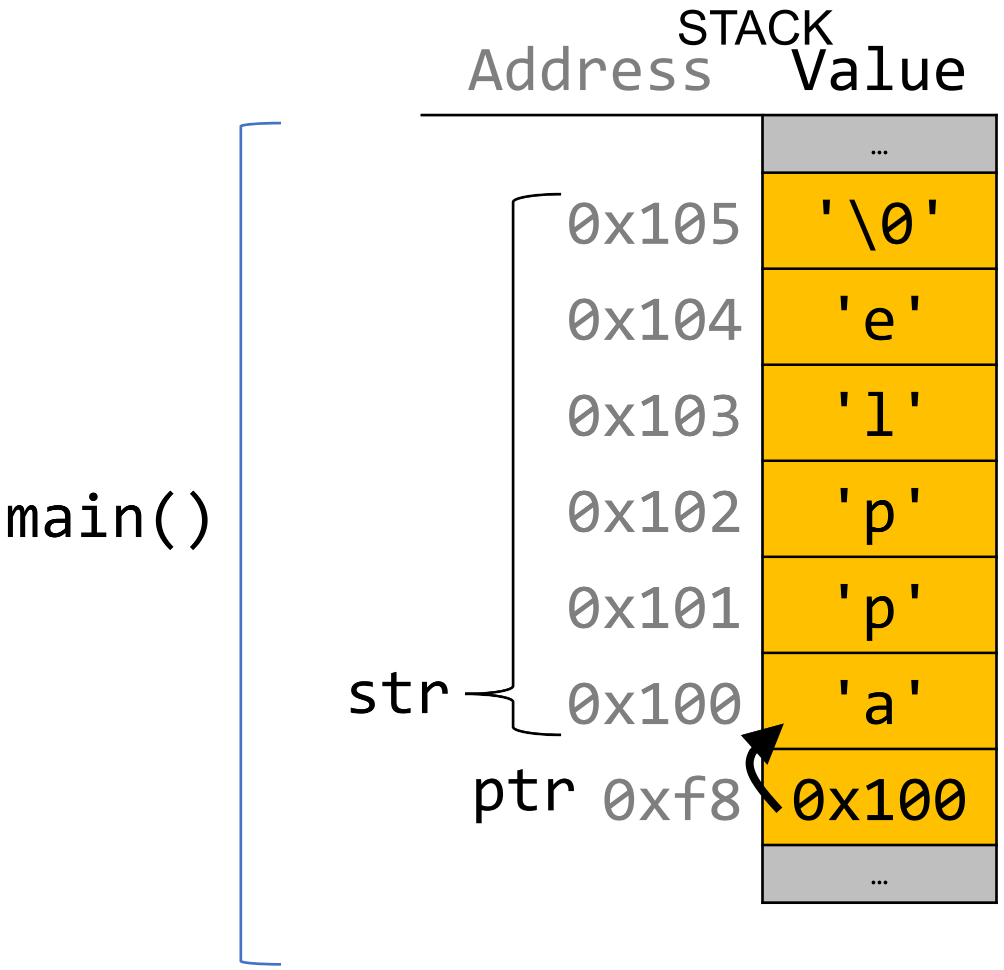
```
int main(int argc, char *argv[]) {
    char str[6];
    strcpy(str, "apple");
    char *ptr = str;
    ...
}
```



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;
      ...
}
```



Read-only Strings

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.

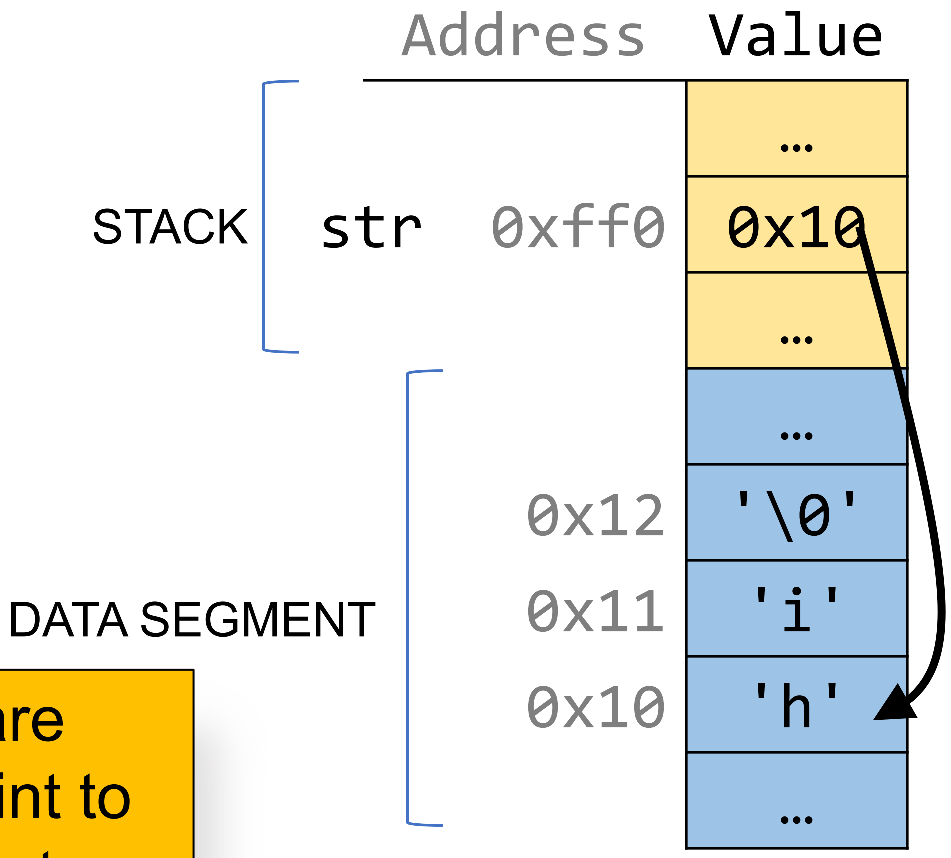
```
char *myString = "Hello, world!";
...
printf("%s", myString);           // Hello, world!
```

Read-only Strings

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*.



NOTE: not all char * strings are read-only. Only ones that point to characters in the data segment are read-only.

Read-only Strings

Read-only strings are convenient to use, but make sure to not use a read-only string in code that tries to modify its characters – it will crash!

```
char *myString = "Hello, world!";
myString[0] = 'h';  // crashes!
```

There's no way in code to check if a string is read-only; it's up to the programmer to properly use strings to avoid these crashes.

- E.g. don't pass in a read-only string as the **src** to **strcpy**

```
strcpy(myString, "Hi");  // crashes!
```

Read-only Strings

A string is read-only if it points to characters that live in the data segment, rather than memory we can modify.

```
char *readOnly = "Hi";

char modifiable[6];
strcpy(modifiable, "Hi");

// is ptr read-only?
char *ptr = modifiable;
// no, because it points to characters on the stack
ptr[0] = 'h';  // ok!
```

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. We can set a **`char *`** equal to another value, because it is a reassign-able pointer.
5. 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.
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.

Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

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) {
    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.

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(__1__) {
    ...
}

int main(int argc, char *argv[]) {
    char *str = "    hello";
    skipSpaces(__2__);
    printf("%s", str);      // should print "hello"
}
```

Exercise 3

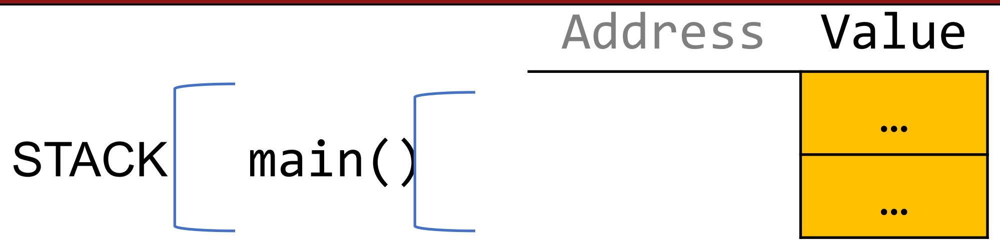
Sometimes, we would like to modify a string's pointer itself, rather than just the characters it points to. E.g. we want to write a function **skipSpaces** that modifies a string pointer to skip past any initial spaces. What should go in each of the blanks?

```
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.

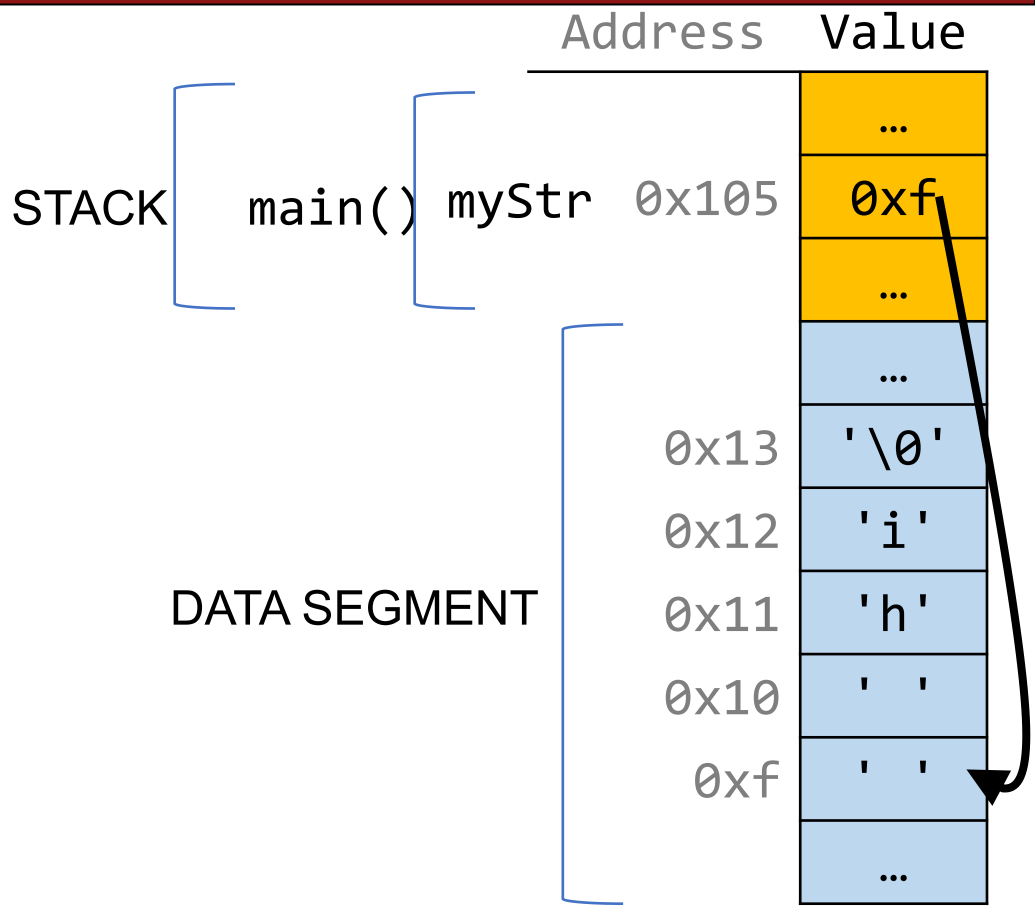
Pointers to Strings

```
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;
}
```



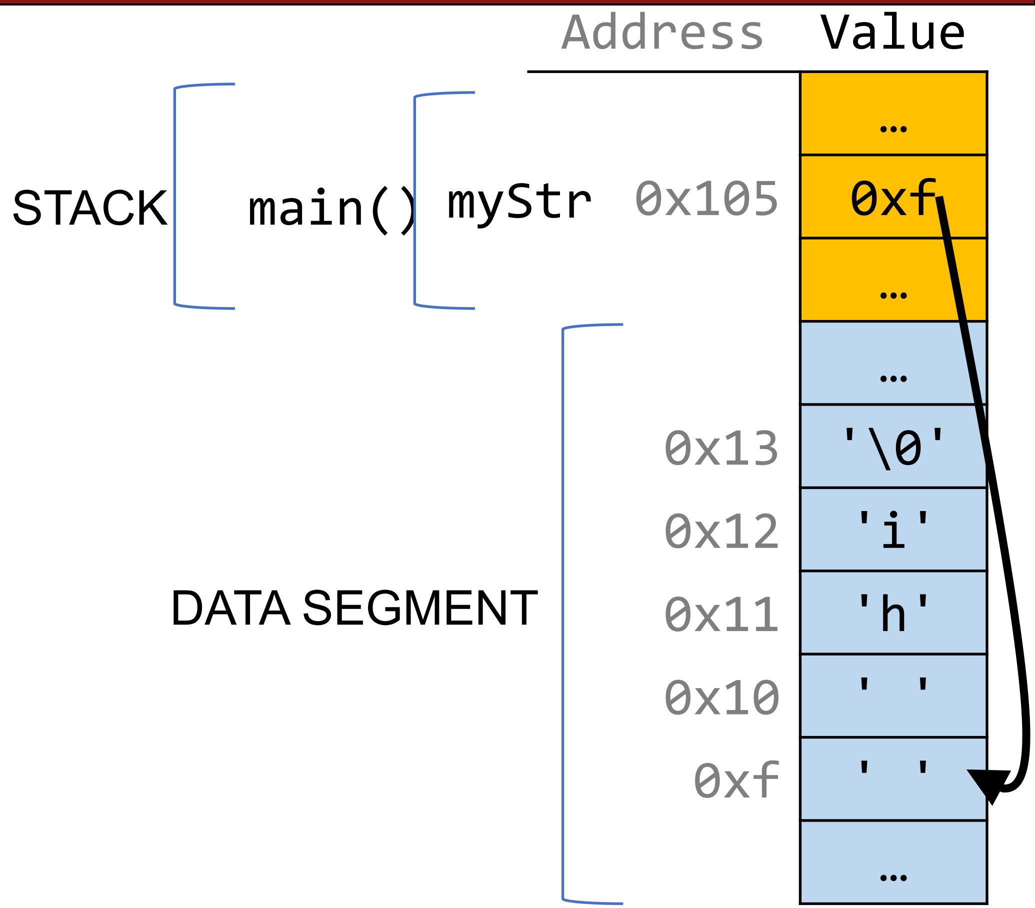
Pointers to Strings

```
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;
}
```



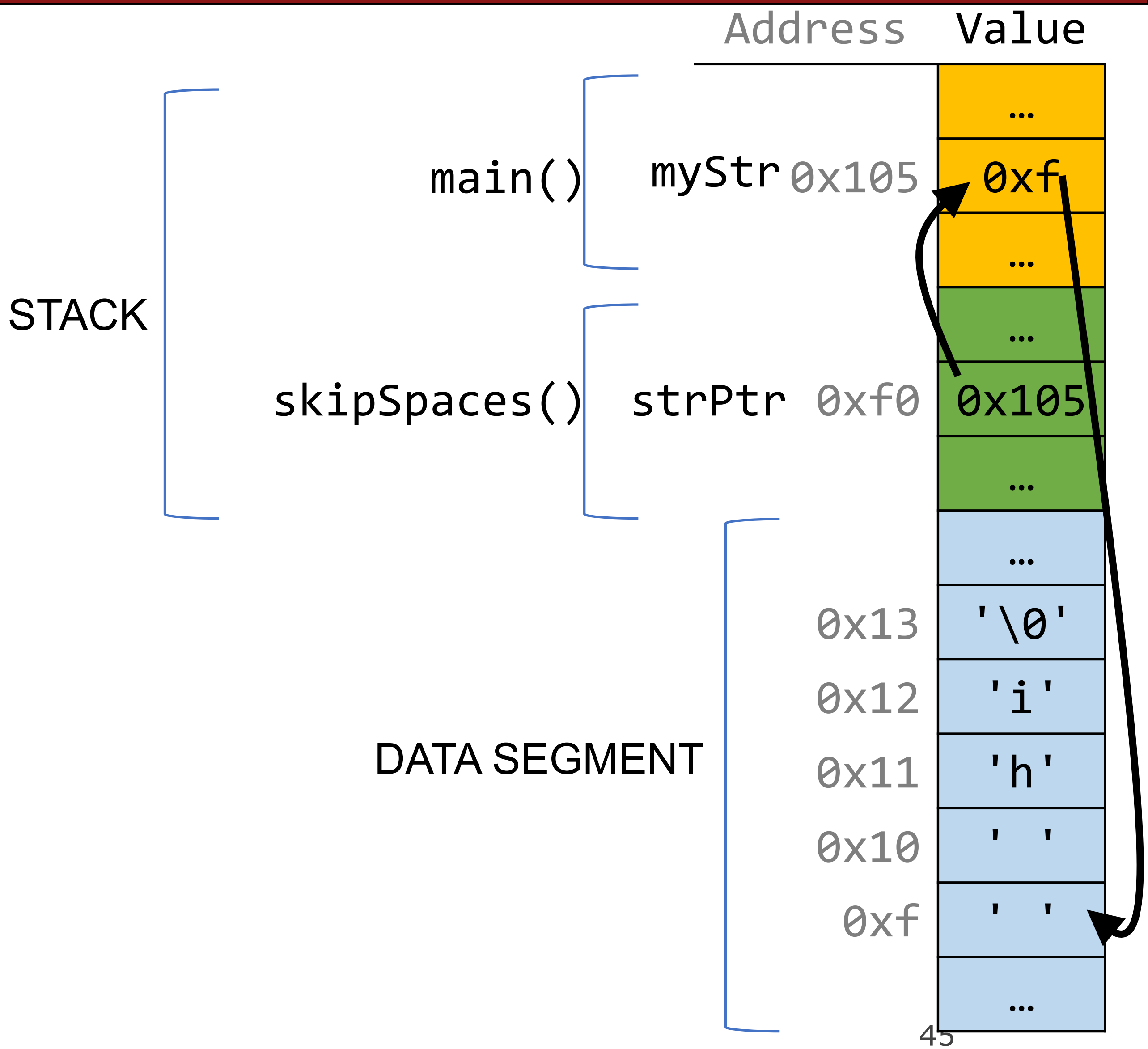
Pointers to Strings

```
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;
}
```



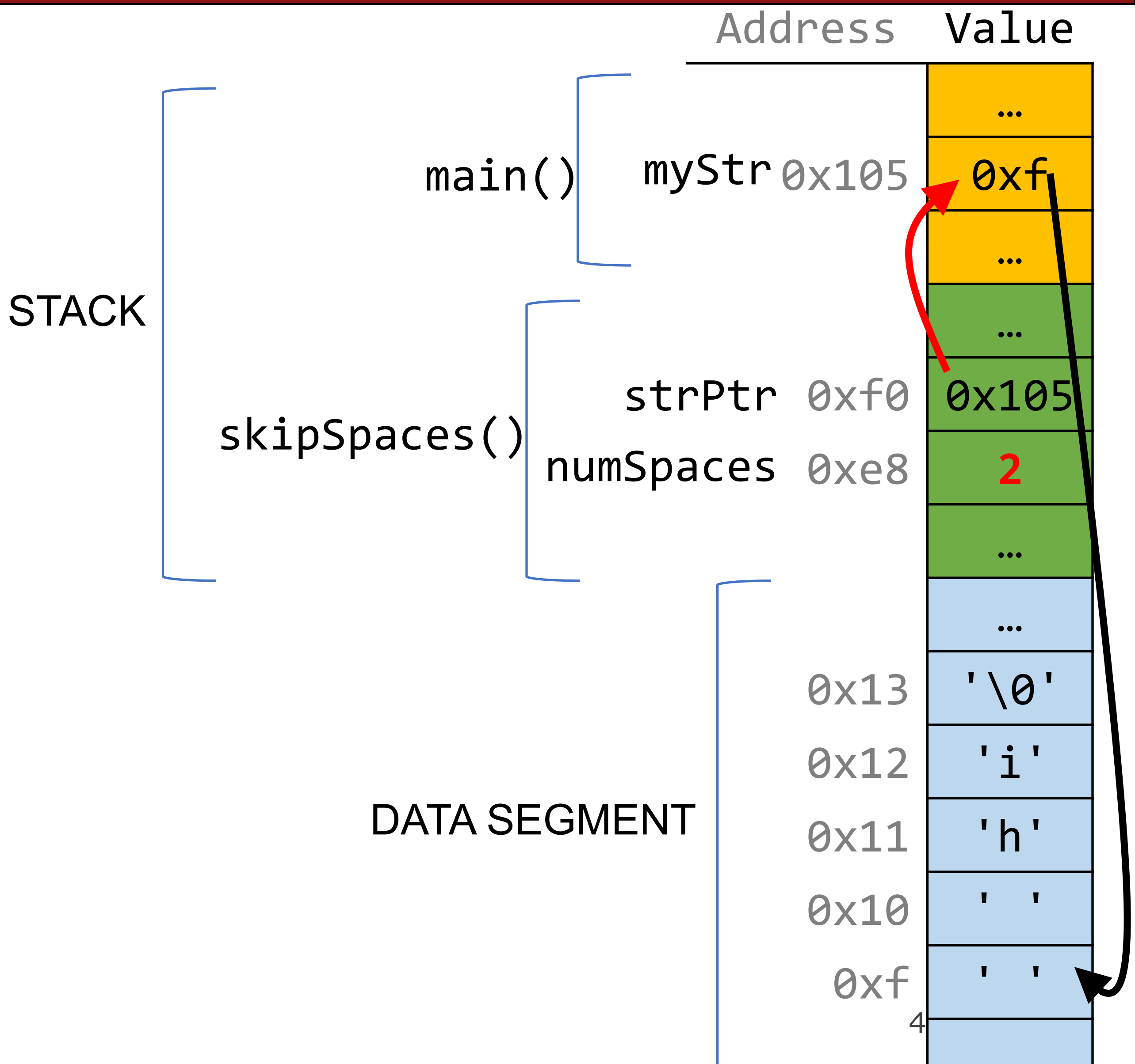
Pointers to Strings

```
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;
}
```



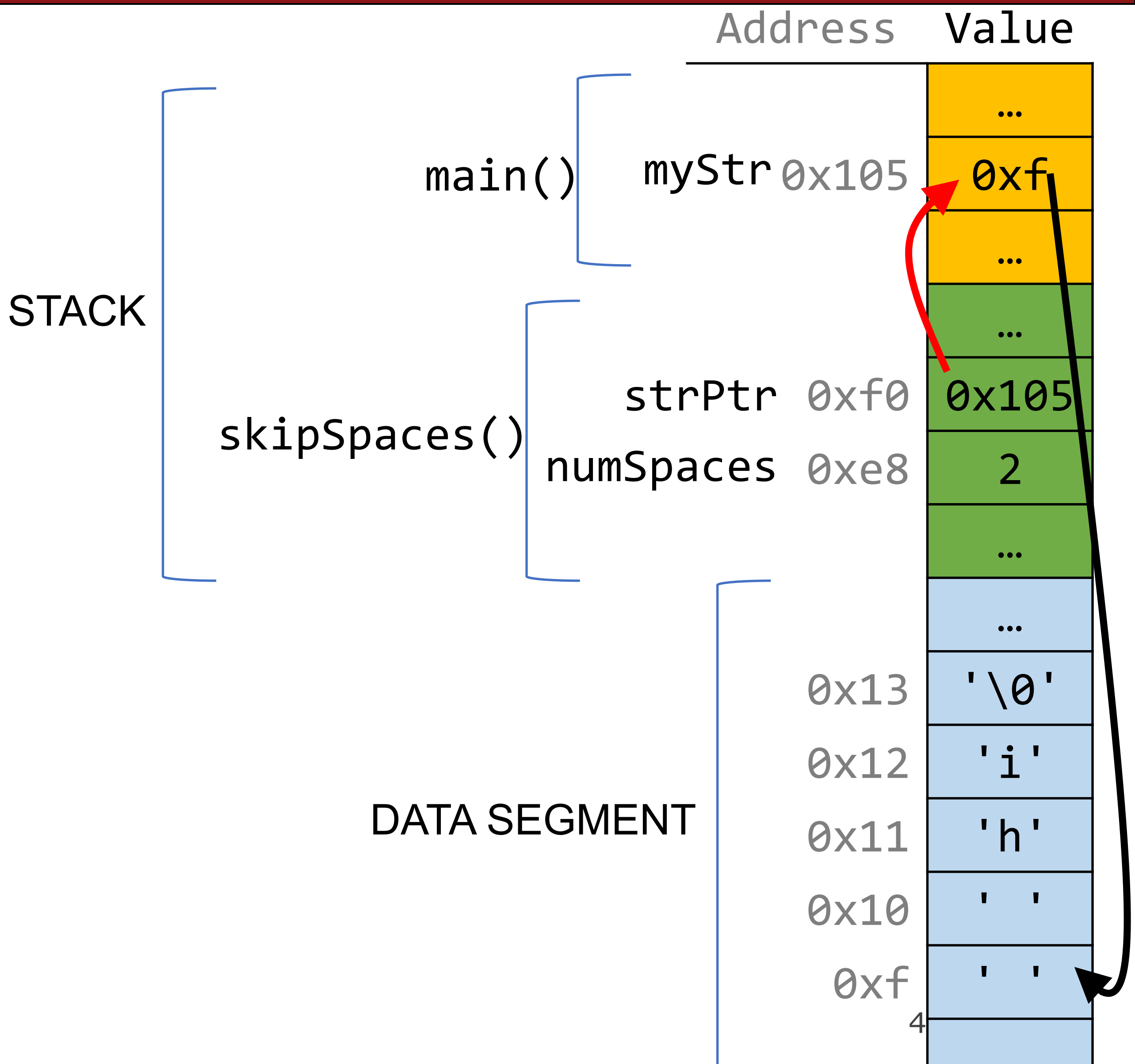
Pointers to Strings

```
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;
}
```



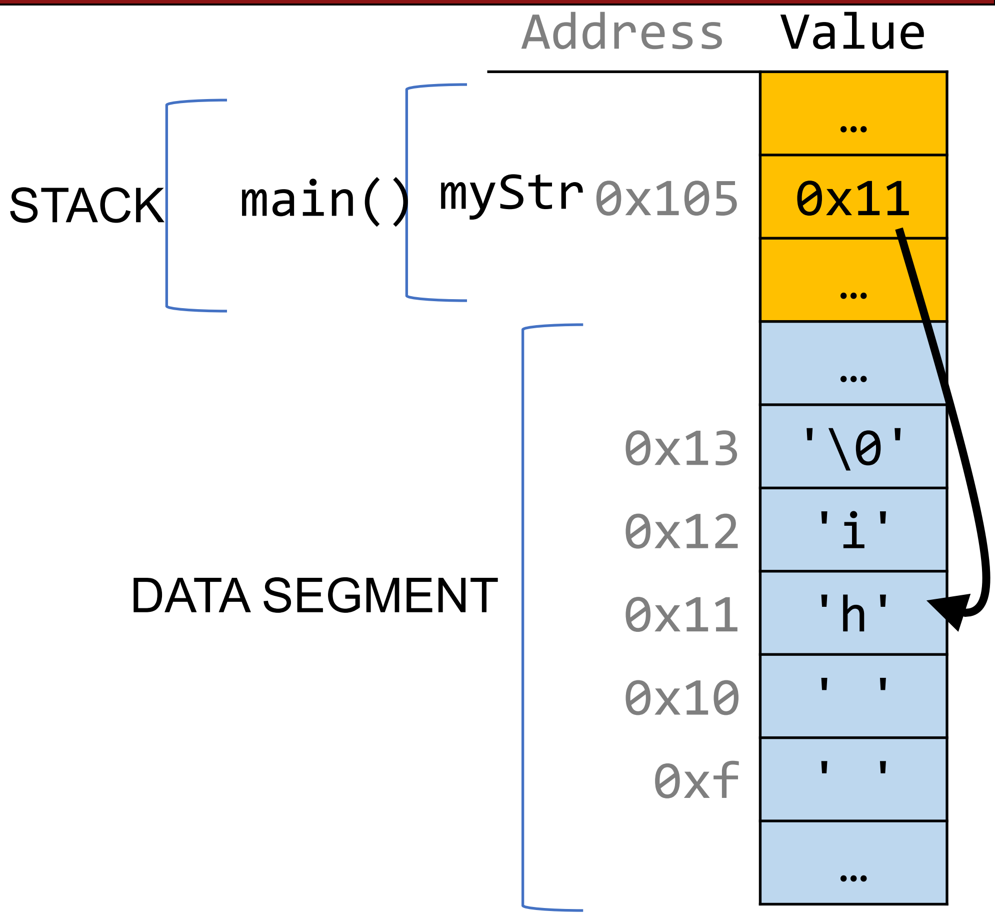
Pointers to Strings

```
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;
}
```



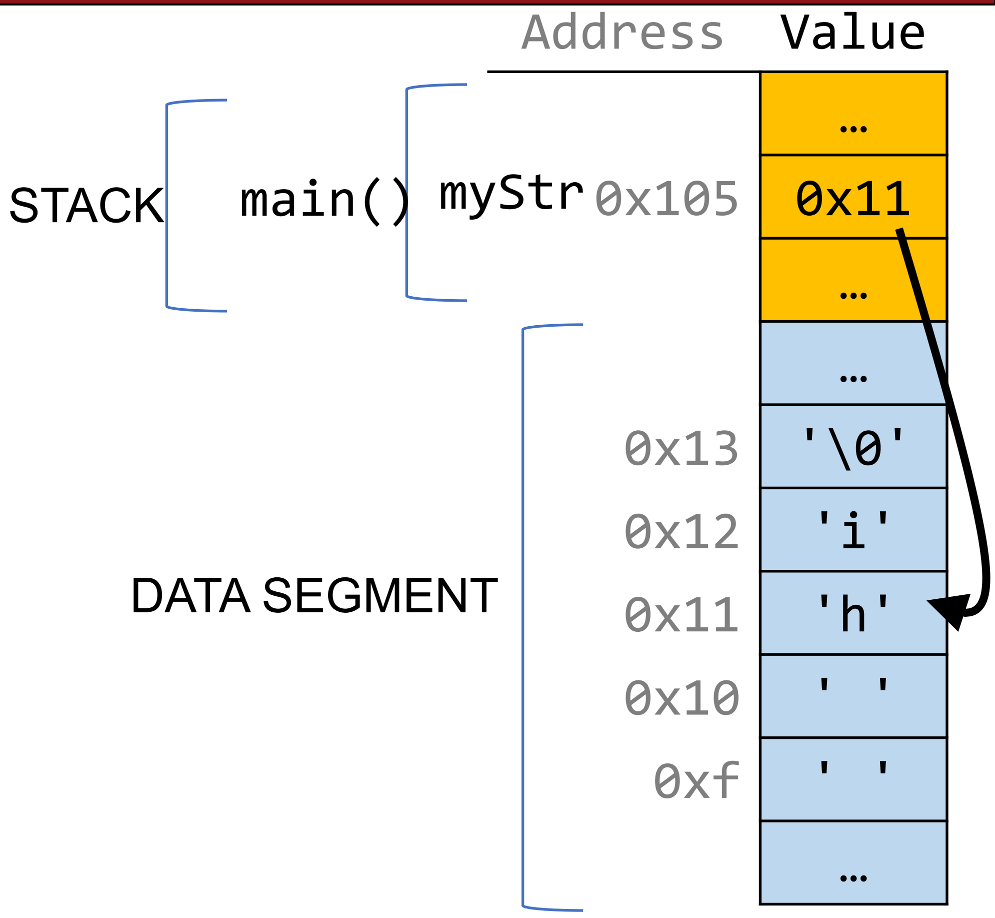
Pointers to Strings

```
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

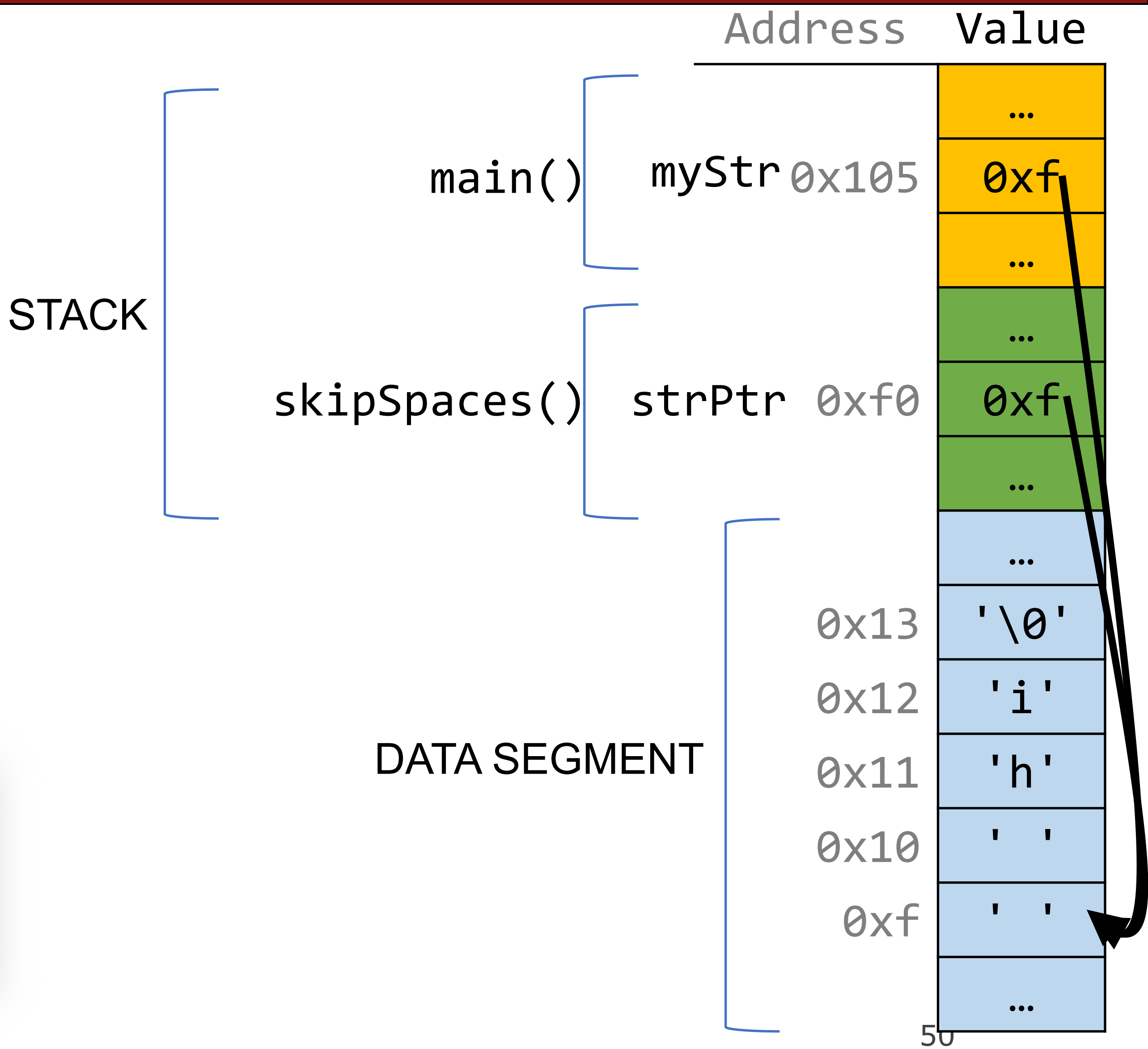
```c
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

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);       //   hi
    return 0;
}
```

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



Recap

- **Finishing up:** Strings and Pointers
- **Now onto:** Double Pointers

Lecture 6 takeaway: pointers let us store the addresses of data and pass them as parameters. We can use double pointers if we want to change the value of a pointer in another function.

Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

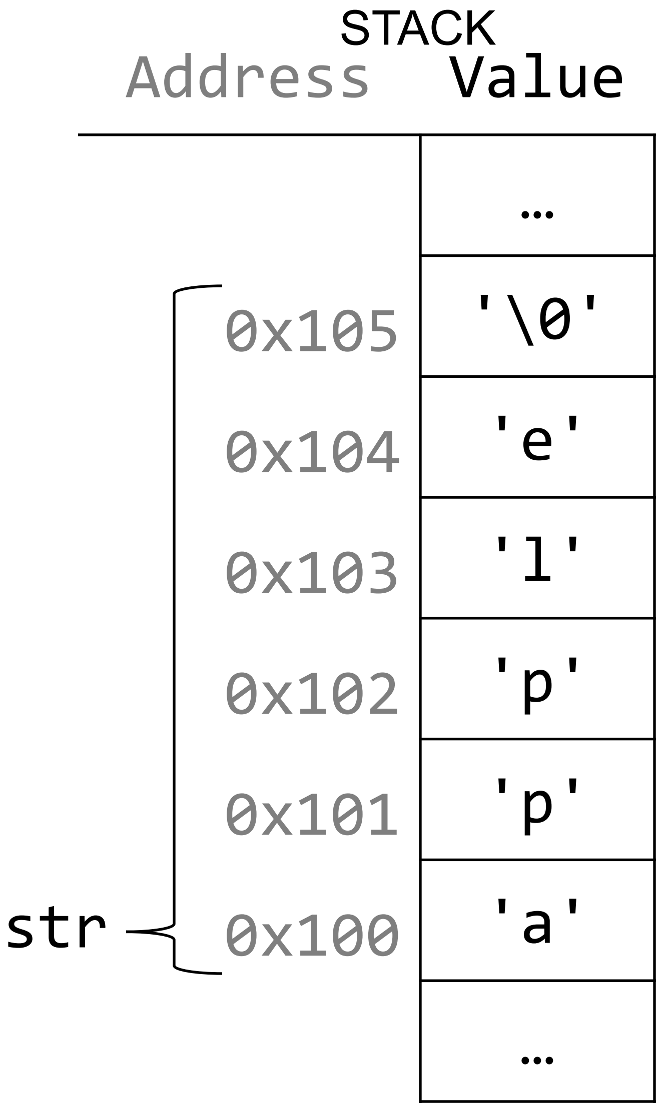
Arrays

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

```c
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!

```c
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.

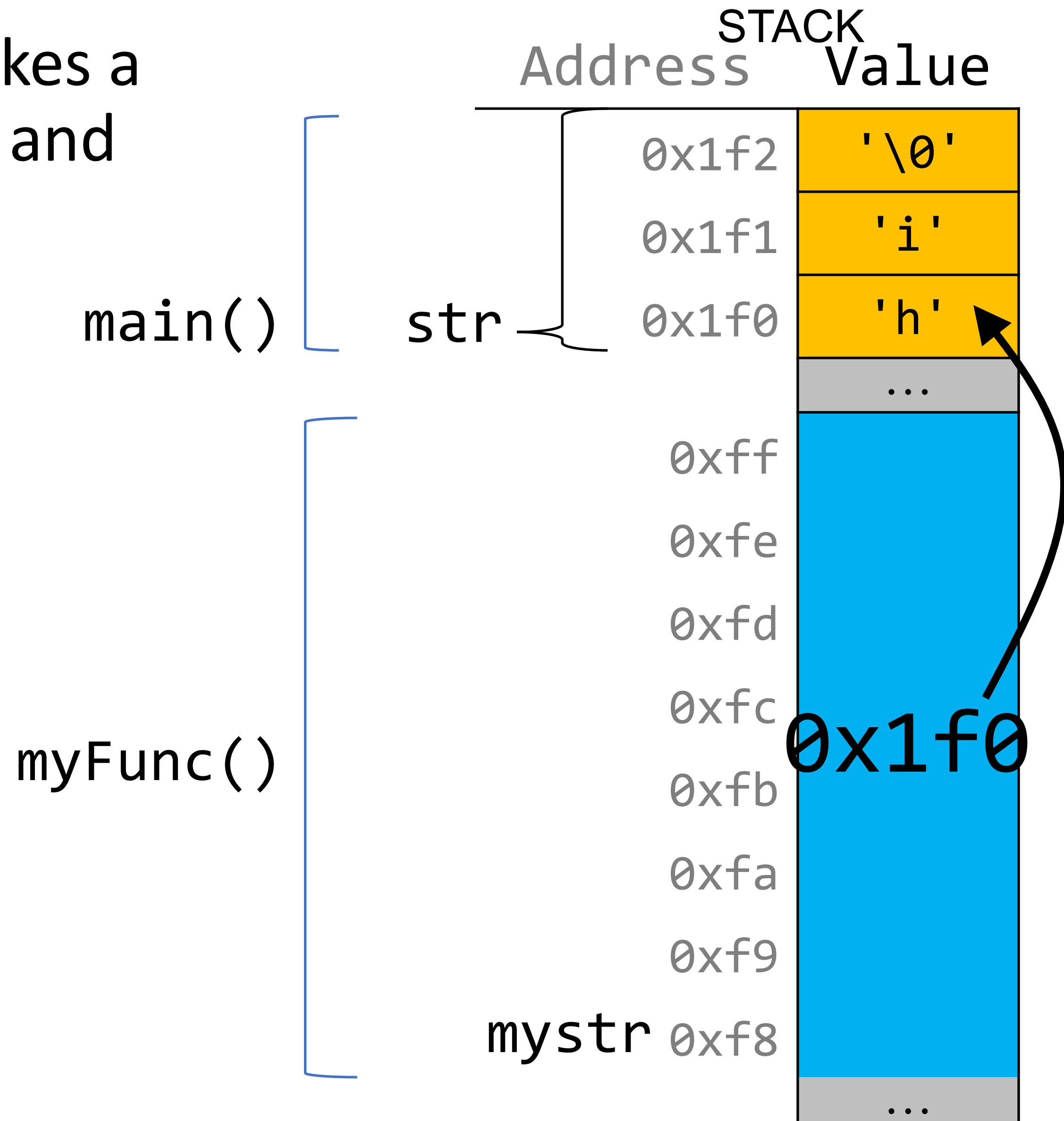
```
int nums[] = {1, 2, 3};
int nums2[] = {4, 5, 6, 7};
nums = nums2; // not allowed!
```

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.

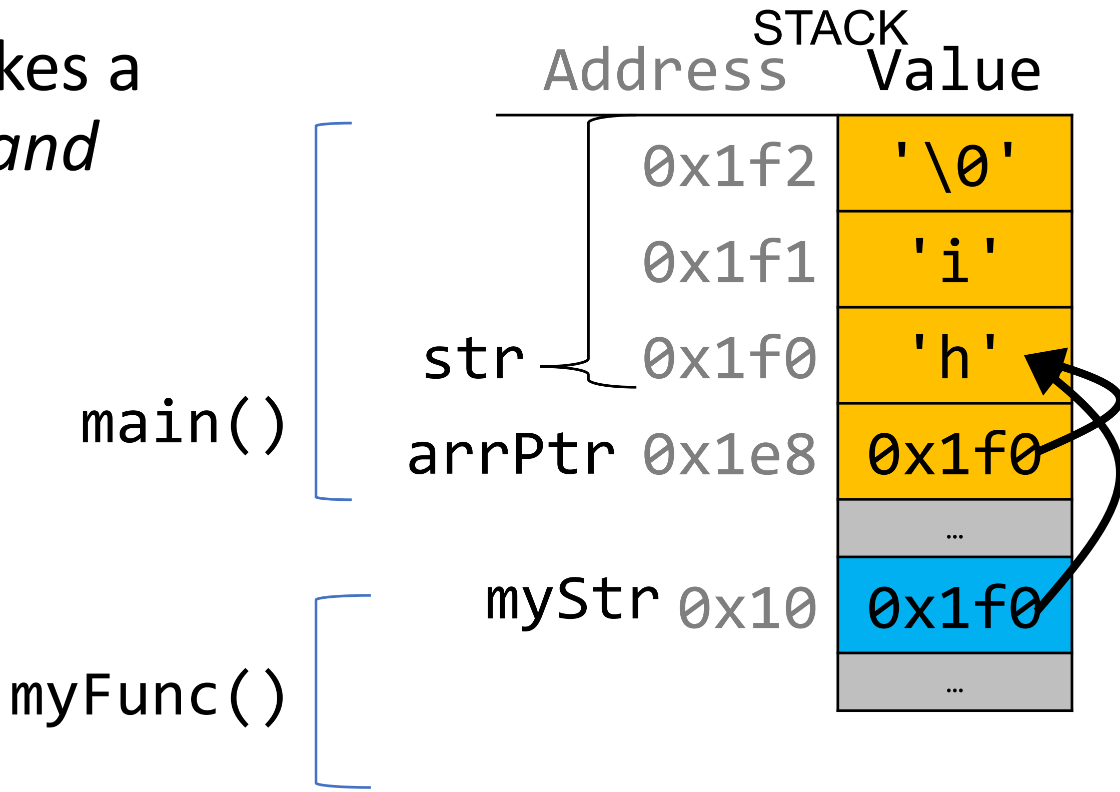
```
void myFunc(char *myStr) {
    ...
}

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.

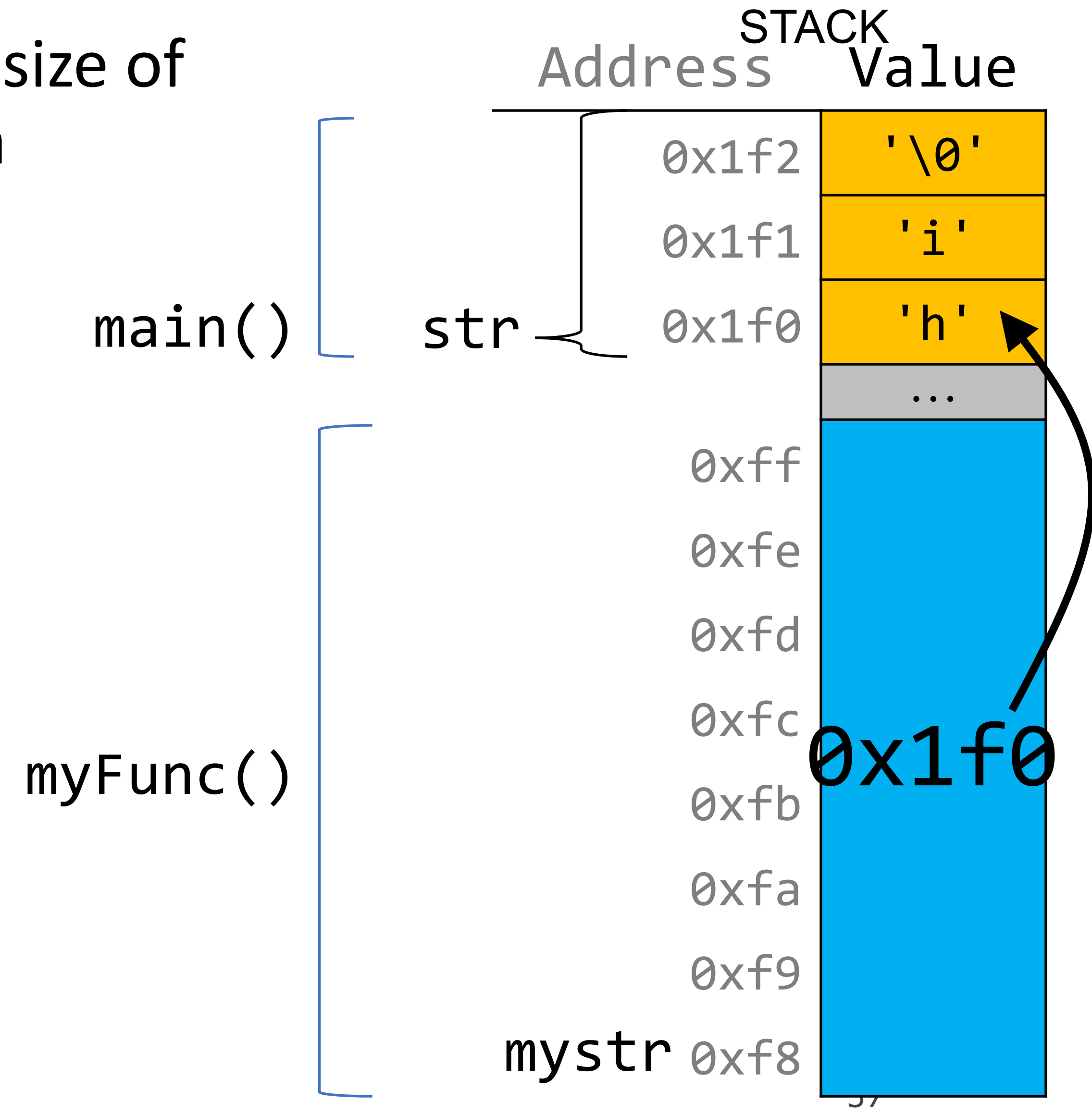
```
void myFunc(char *myStr) {
      …
}

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 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 an 8 byte address.
- Arrays ”decay to pointers” when you perform arithmetic or pass as parameters.
- You can set a pointer equal to an array; that pointer will point to the array’s first element
- &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

Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

Arrays Of Pointers

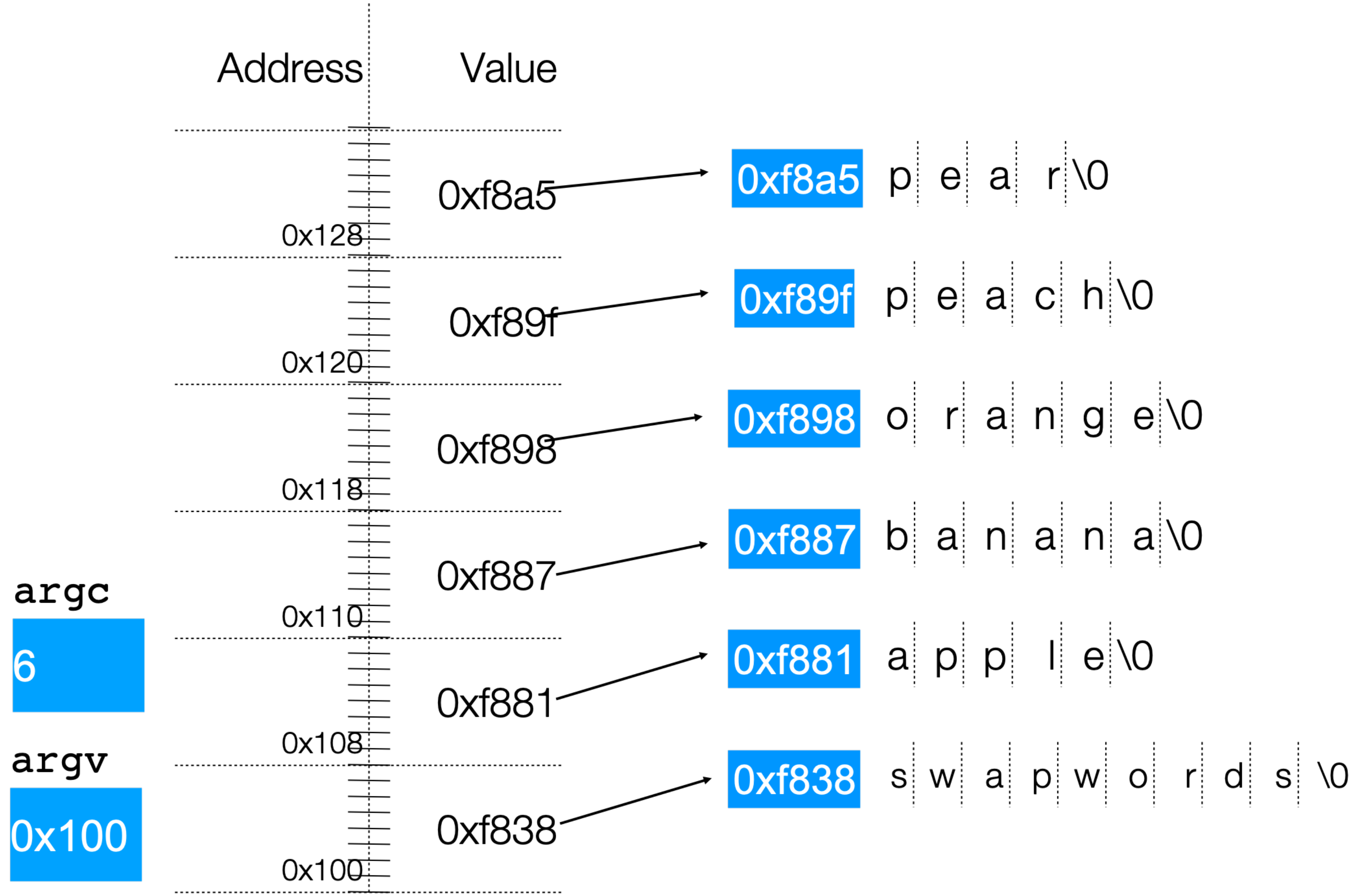
You can make an array of pointers to e.g. group multiple strings together:

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

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

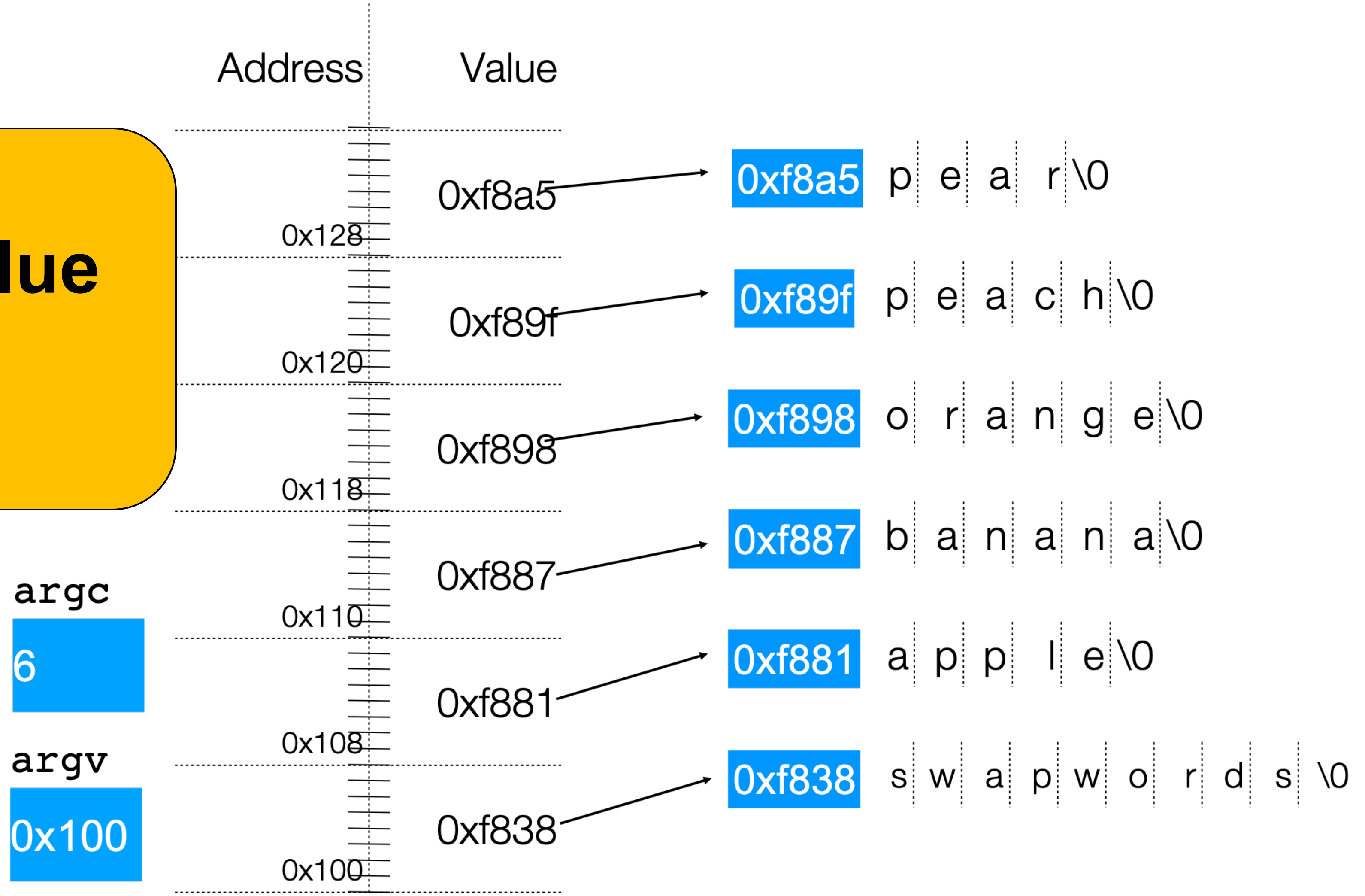
```
char *str0 = stringArray[0];     // first char *
```

Arrays Of Pointers



Arrays Of Pointers

Question:
What's the value of argv[0]?



Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

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
```

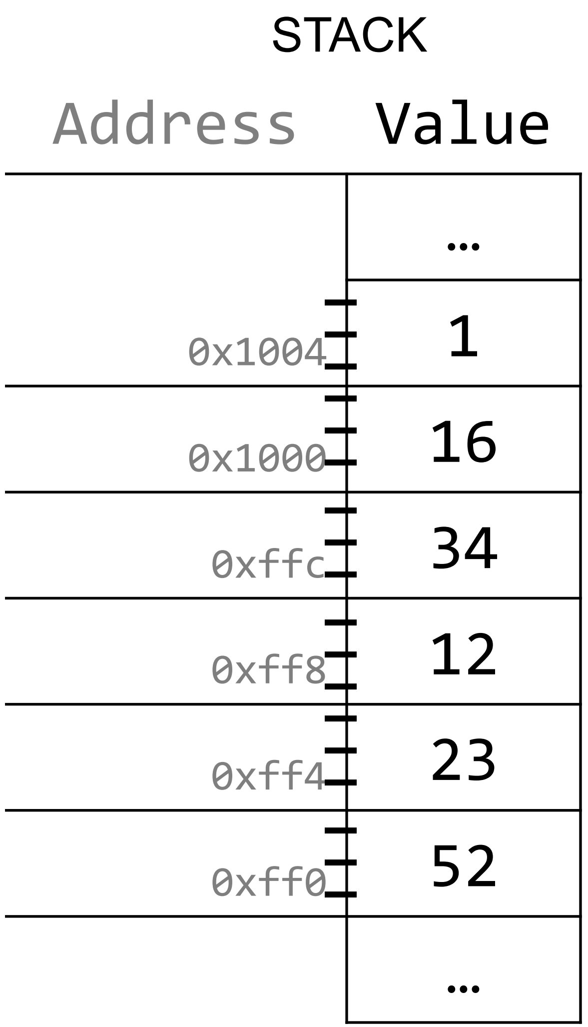
DATA SEGMENT

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*.

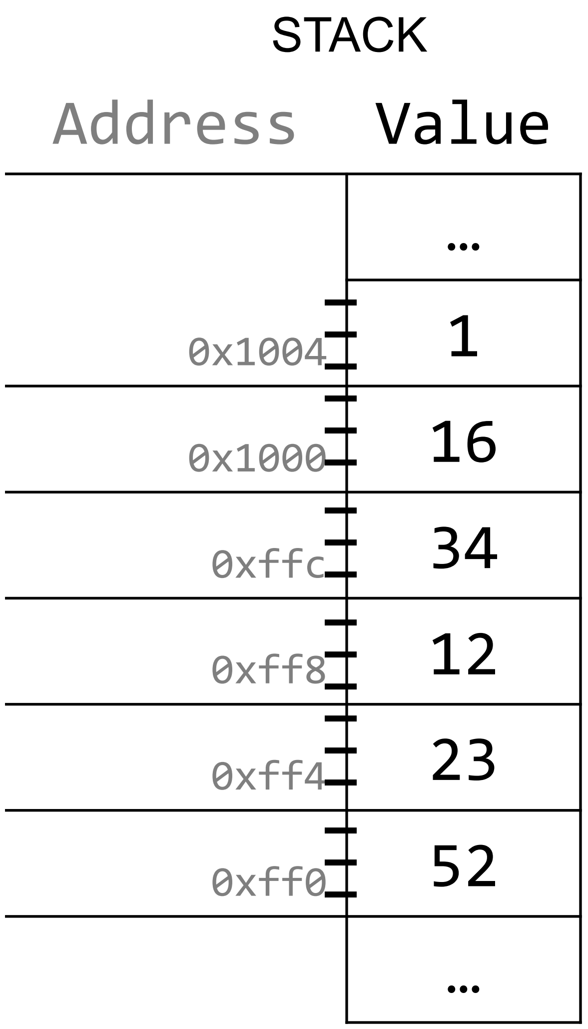
```c
// nums points to an int array
int *nums = …              // e.g. 0xff0
int *nums1 = nums + 1;  // e.g. 0xff4
int *nums3 = nums + 3;  // e.g. 0xffc

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



Pointer Arithmetic

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

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

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



Pointer Arithmetic

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

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

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

DATA SEGMENT

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

Pointer Arithmetic

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

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

STACK

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

Pointer Arithmetic

How does the code know how many bytes it should look at once it visits an address? At compile time, C can figure out the sizes of different data types, and the sizes of what they point to.

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

// C knows 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? At compile time, C can figure out the sizes of different data types, and the sizes of what they point to.

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

// C knows to add 4 bytes here
int *intPtr = nums + 1;

char str[6];
strcpy(str, "CS107");

// C knows to add 1 byte here
char *charPtr = str + 1;
```

Lecture Plan


```
cp -r /afs/ir/class/cs107/lecture-code/lect06 .
```

Const

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

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

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

Const

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

```
char str[6];
strcpy(str, "Hello");
const char *s = str;

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

Const

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

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

Const

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

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

Const

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

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

Const

const can be confusing to interpret in some variable types.

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

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

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

Structs

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

```
struct date {           // declaring a struct type
    int month;
    int day;            // members of each date structure
};
…
struct date today;                     // construct structure instances
today.month = 1;
today.day = 28;
struct date new_years_eve = {12, 31};   // shorter initializer syntax
```

Structs

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

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

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

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

Structs

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

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

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

Structs

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

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

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

Structs

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

```
void advance_day(date *d) {
      d->day++;  // equivalent to (*d).day++;
}

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

Structs

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

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

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

Structs

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

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

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

Arrays of Structs

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

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

…

my_struct array_of_structs[5];
```

Arrays of Structs

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

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

…

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

Arrays of Structs

You can also set each field individually.

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

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

Ternary Operator

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

```
condition ? expressionIfTrue : expressionIfFalse
```

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

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

Recap

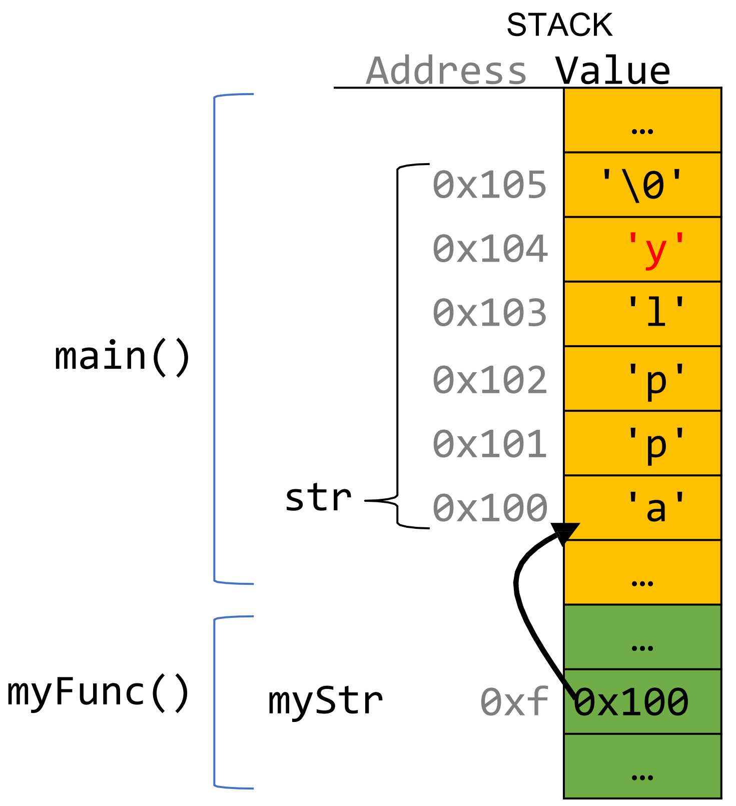
- Pointers and Parameters
- Double Pointers
- Arrays in Memory
- Arrays of Pointers
- Pointer Arithmetic
- Other topics: **const**, **struct** and ternary

Plan For Today

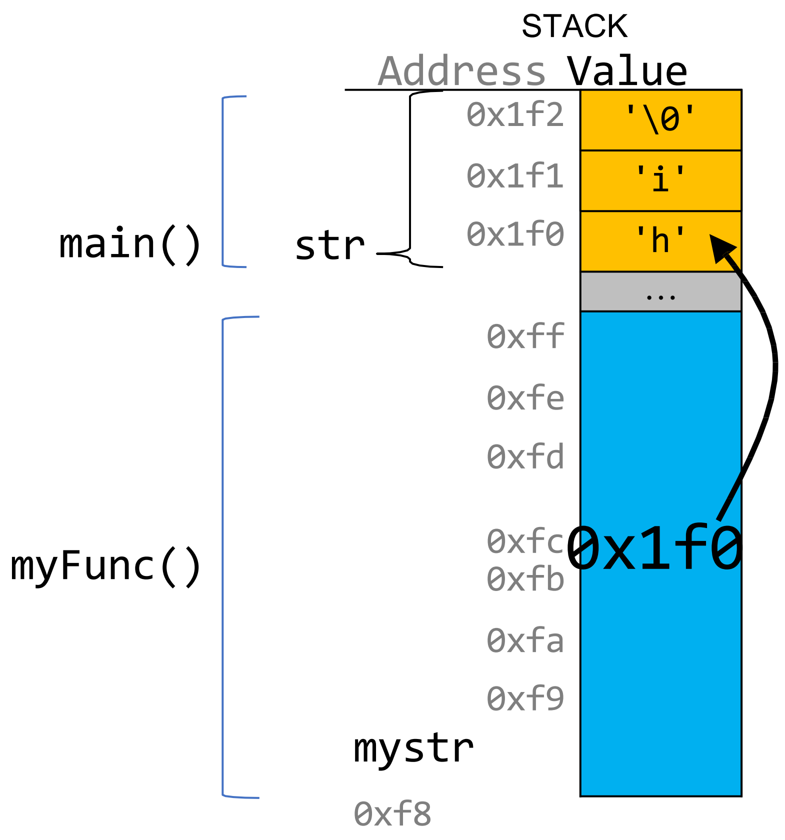
- **10 minutes:** general review
- **5 minutes:** post questions or comments on Ed for what we should discuss

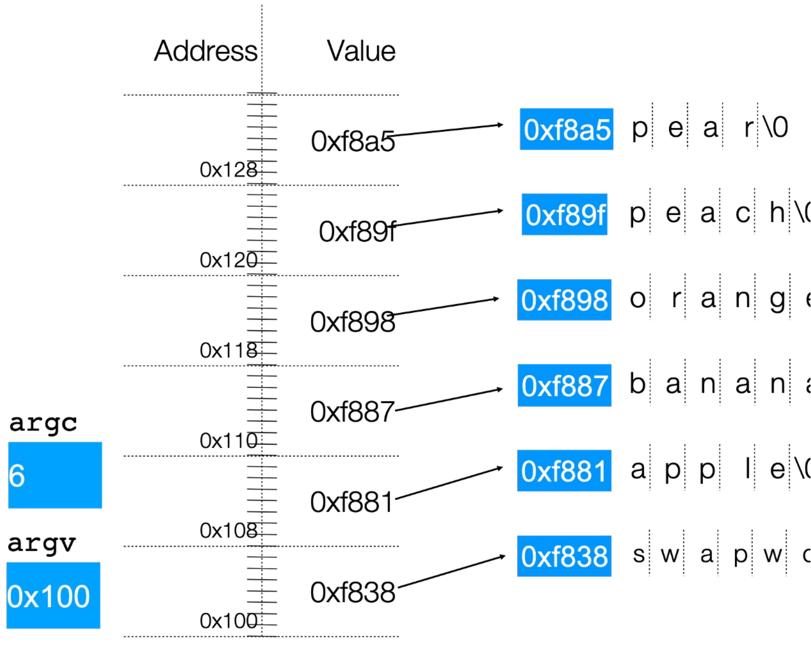
Lecture 6 takeaway: pointers let us store the addresses of data and pass them as parameters. We can perform arithmetic with pointers to change where they point to. Arrays in C also “decay to pointers” as parameters and in arithmetic expressions.

How to draw memory diagrams?



Slide 34





Choose whatever style is convenient for you, keeping in mind that (1) memory is contiguous, and (2) C types are different sizes.

Is there a difference?

```
size_t get_total_strlen(char *strs[], size_t num) {
    …
}
```

Intent: `strs` is an array of strings

```
void *skip_spaces(char **p_str) {
    …
}
```

Intent: `p_str` is a pointer to a string

No difference to the compiler—it's char**!
But it clarifies the ***intent*** of a function/a parameter ***for the programmer***.

Pointer arithmetic

Array indexing is "syntactic sugar" for pointer arithmetic:

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

⚠️ Pointer arithmeec **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.

Translating C into English

* If **declaration**: “pointer”
ex: `int *` is "pointer to an int”
If **operation**: "dereference/the value at address”
ex: `*num` is "the value at address num"

& “address of”

<ptr name> address

<arr name> address (except sizeof)

```
int arr[] = {3, 4, -1, 2};      // initializes stack array
                                // with 4 ints

int *ptr0 =    arr;
int *elt0 =    *arr;
int elt   =    *(arr + 3);
int **ptr1=.   &ptr;
```

Type check with a diagram!

Translating C into English

*	If **declaration**: “pointer” ex: `int *` is "pointer to an int” If **operation**: "dereference/the value at address” ex: `*num` is "the value at address num"

&	“address of”

`<ptr name>`	address

`<arr name>`	address (except sizeof)

```
int arr[] = {3, 4, -1, 2}; // initializes stack array
                           // with 4 ints

int *ptr0 =    arr;
int *elt0 =    *arr;
int elt   =    *(arr + 3);
int **ptr1=.   &ptr;
```

Address `arr`

Value at address `arr`

The value at address 3 `ints` after address `arr`

address of `ptr`

Type check with a diagram!

Plan For Today

- **10 minutes:** general review
- **5 minutes: Any questions?**

Lecture 6 takeaway: pointers let us store the addresses of data and pass them as parameters. We can perform arithmetic with pointers to change where they point to.

Arrays in C also “decay to pointers” as parameters and in arithmetic expressions.

Extra Practice

2. char* vs char[ ] exercises

Suppose we use a variable `str` as follows:

```
  // initialize as below
A str = str + 1;
B str[1] = 'u’;
C printf("%s", str)
```

For each of the following initializations:

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

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

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

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

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

2. char* vs char[ ] exercises

Suppose we use a variable str as follows:

```
      // initialize as below
A     str = str + 1;
B     str[1] = 'u';
C     printf("%s", str)
```

For each of the following initializations:

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

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

Line A: Compile error (cannot reassign array)

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

Line B: Segmentation fault (string literal)

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

Prints eulo3

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

Line B: Segmentation fault (string literal)

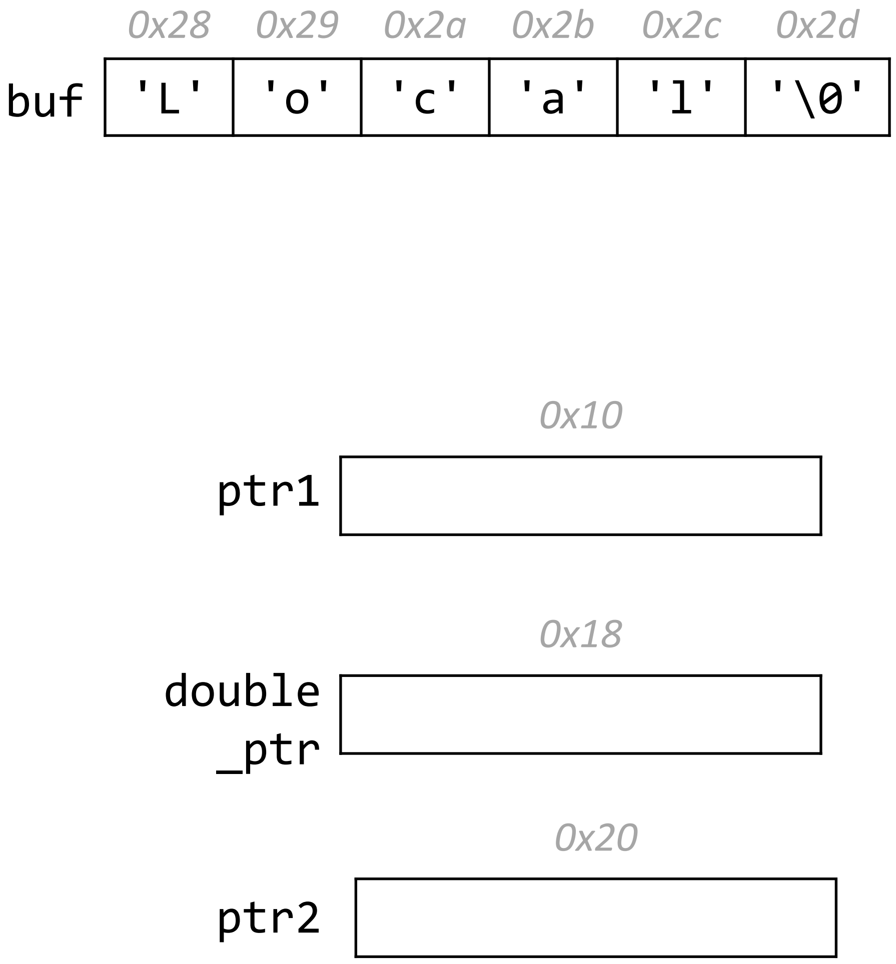
3. Bonus: Tricky addresses

```
void tricky_addresses() {
  char buf[] = "Local";
  char *ptr1 = buf;
  char **double_ptr = &ptr1;
  printf("ptr1's value:     %p\n", ptr1);
  printf("ptr1’s deref    : %c\n", *ptr1);
  printf("        address:   %p\n", &ptr1);
  printf("double_ptr value: %p\n", double_ptr);
  printf("buf's address:    %p\n", &buf);

  char *ptr2 = &buf;
  printf("ptr2's value:     %s\n", ptr2);
}
```

What is stored in each variable?

3. Bonus: Tricky addresses

```c
1  void tricky_addresses() {
2    char buf[] = "Local";
3    char *ptr1 = buf;
4    char **double_ptr = &ptr1;
5    printf("ptr1's value:     %p\n", ptr1);
6    printf("ptr1’s deref    : %c\n", *ptr1);
7    printf("         address:   %p\n", &ptr1);
8    printf("double_ptr value: %p\n", double_ptr);
9    printf("buf's address:    %p\n", &buf);

10   char *ptr2 = &buf;
11   printf("ptr2's value:     %s\n", ptr2);
12 }
```

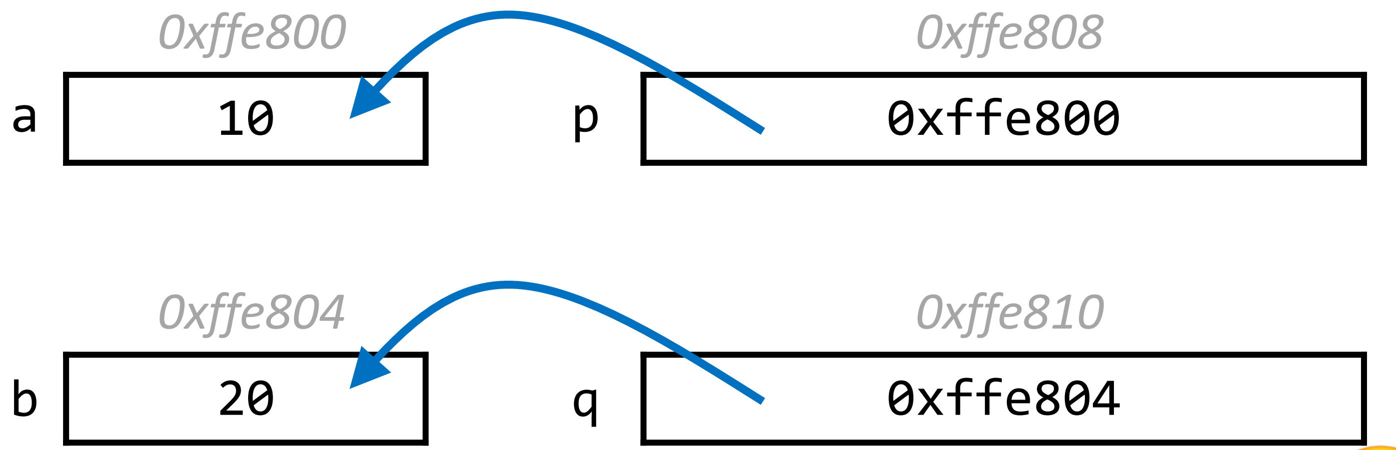


While Line 10 raises a compiler warning, functionally it will still work—because pointers are **addresses**.

Pen and paper: A * Wars Story

```
1 void binky() {
2       int a = 10;
3       int b = 20;
4       int *p = &a;
5       int *q = &b;
6
7       *p = *q;
8       p = q;
9 }
```

- Lines 2-5: Draw a diagram.
- Line 7: Update your diagram.
- Line 8: Update your diagram.



Pen and paper: A * Wars Story

```
1 void binky() {
2       int a = 10;
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4       int *p = &a;
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6
7       *p = *q;
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```

- Lines 2-5: Draw a diagram.
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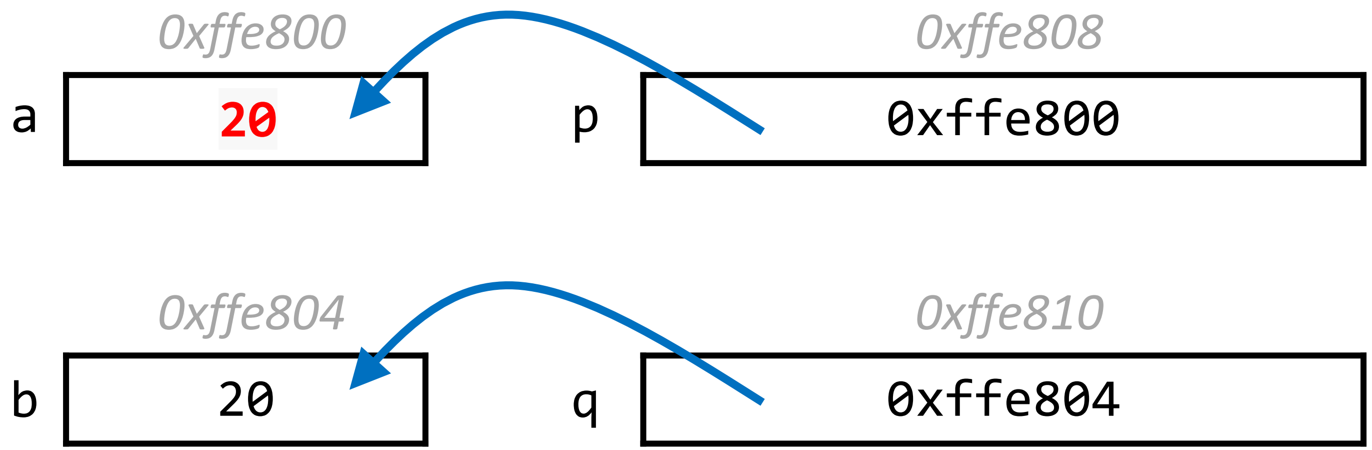
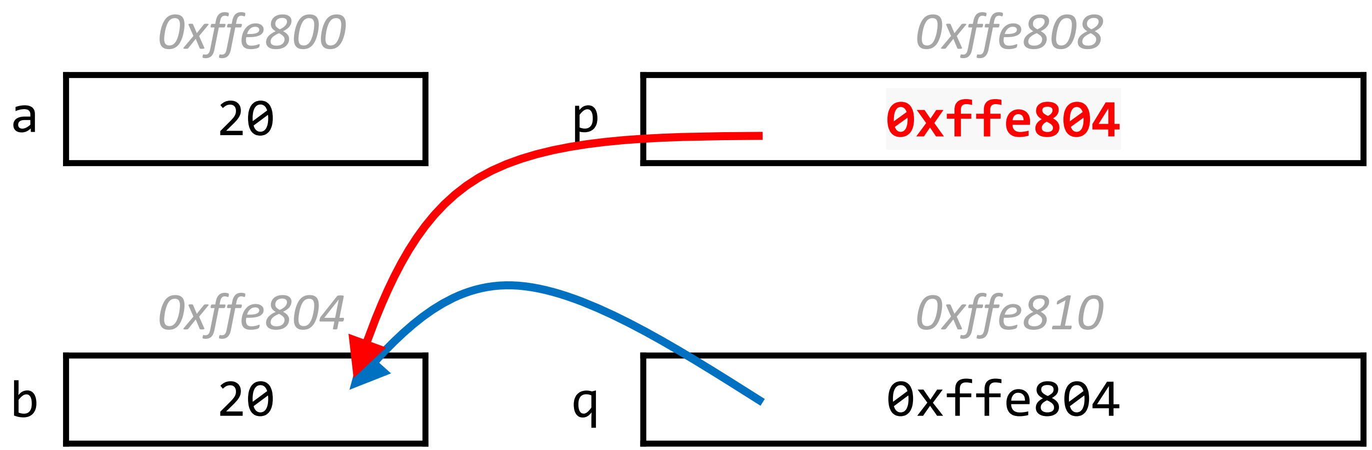


Pen and paper: A * Wars Story

```
1 void binky() {
2       int a = 10;
3       int b = 20;
4       int *p = &a;
5       int *q = &b;
6
7       *p = *q;
8       p = q;
9 }
```

- Lines 2-5: Draw a diagram.
- Line 7: Update your diagram.
- Line 8: Update your diagram.



* Wars: Episode I (of 2)

In variable **declaration**, * creates a **pointer**.

```
char ch = 'r';
```

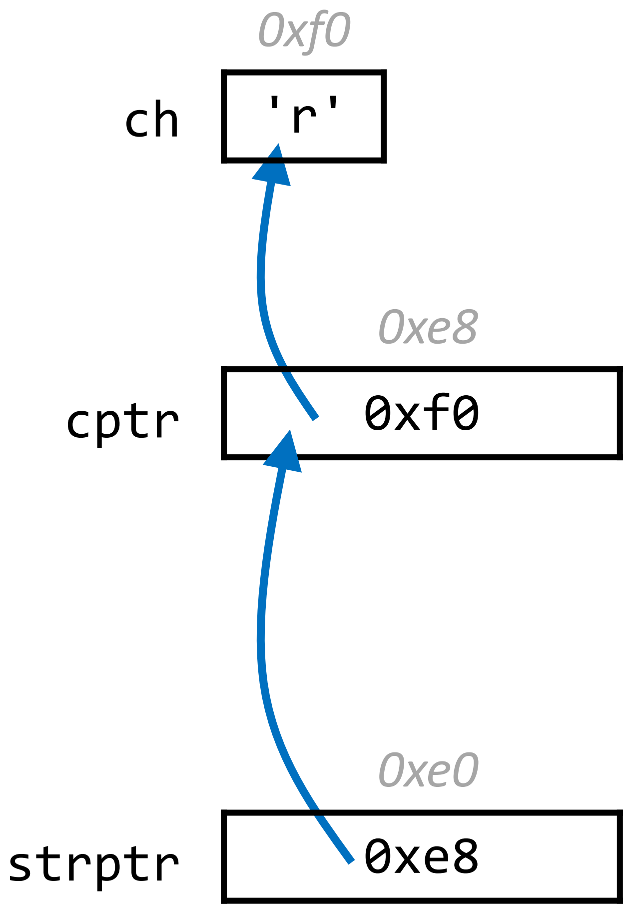
`ch` stores a char

```
char *cptr = &ch;
```

`cptr` stores an address of a char
(**points to** a char)

```
char **strptr = &cptr;
```

`strptr` stores an address of a char *
(**points to** a char *)



* Wars: Episode II (of 2)

In **reading values from/storing values**, * **dereferences** a pointer.

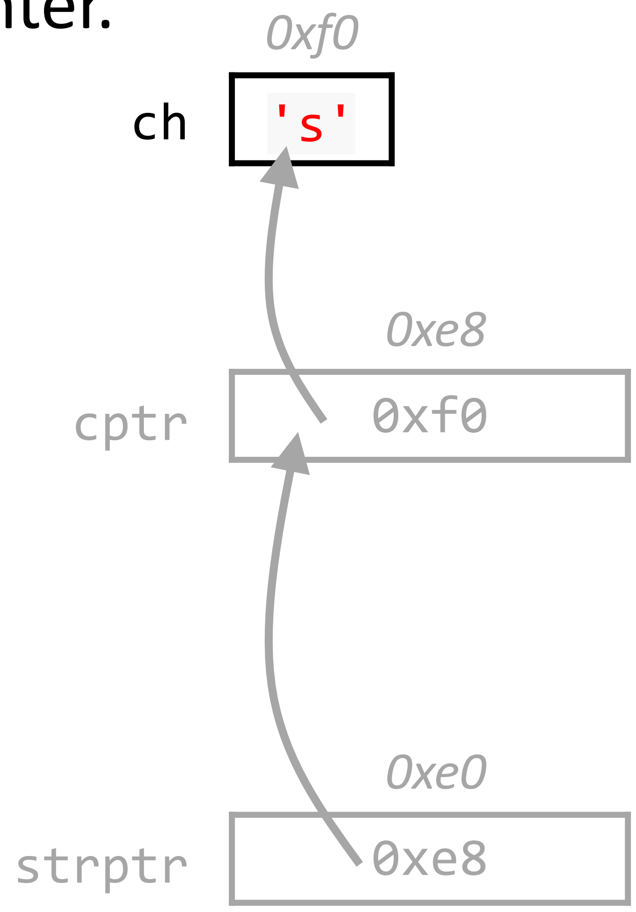
```
char ch = 'r';
ch = ch + 1;
```

Increment value stored in ch

```
char *cptr = &ch;



char **strptr = &cptr;
```



* Wars: Episode II (of 2)

In **reading values from/storing values**, * **dereferences** a pointer.

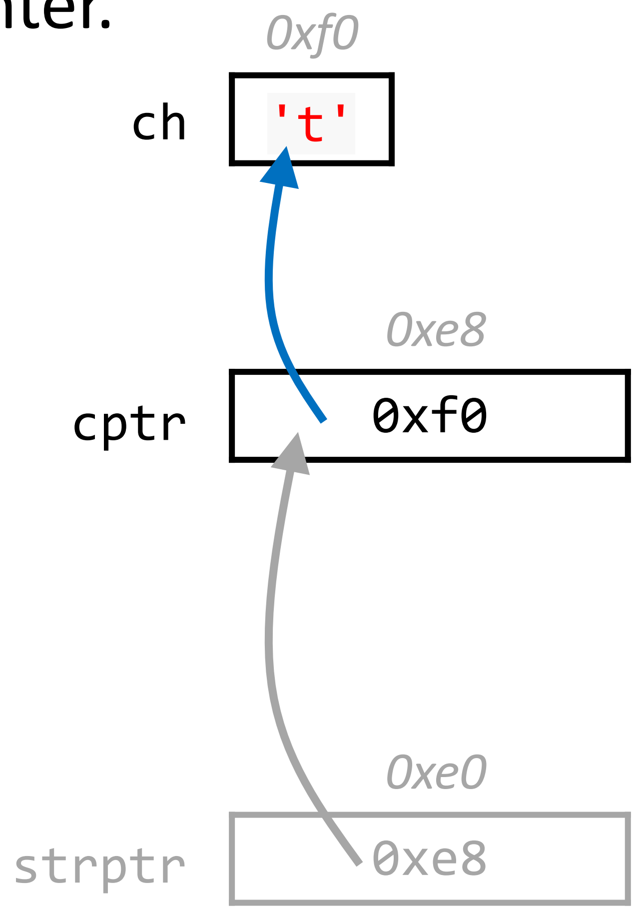
```
char ch = 'r';
ch = ch + 1;
```

Increment value stored in ch

```
char *cptr = &ch;
*cptr = *cptr + 1;
```

Increment value stored at memory address in cptr (increment char **pointed to**)

```
char **strptr = &cptr;
```



* Wars: Episode II (of 2)

In **reading values from/storing values**, * **dereferences** a pointer.

```
char ch = 'r';
ch = ch + 1;
```

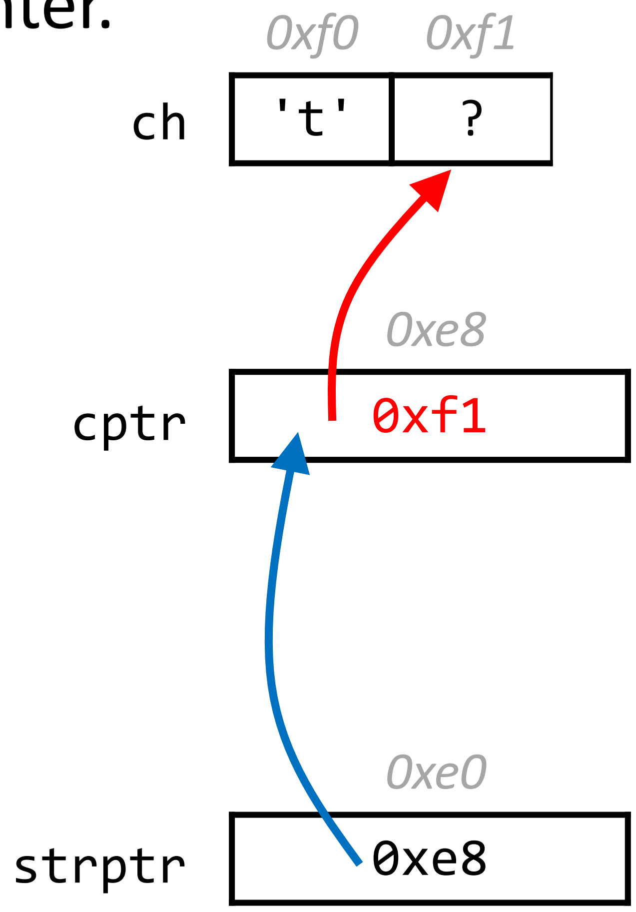
Increment value stored in ch

```
char *cptr = &ch;
*cptr = *cptr + 1;
```

Increment value stored at memory address in cptr (increment char **pointed to**)

```
char **strptr = &cptr;
*strptr = *strptr + 1;
```

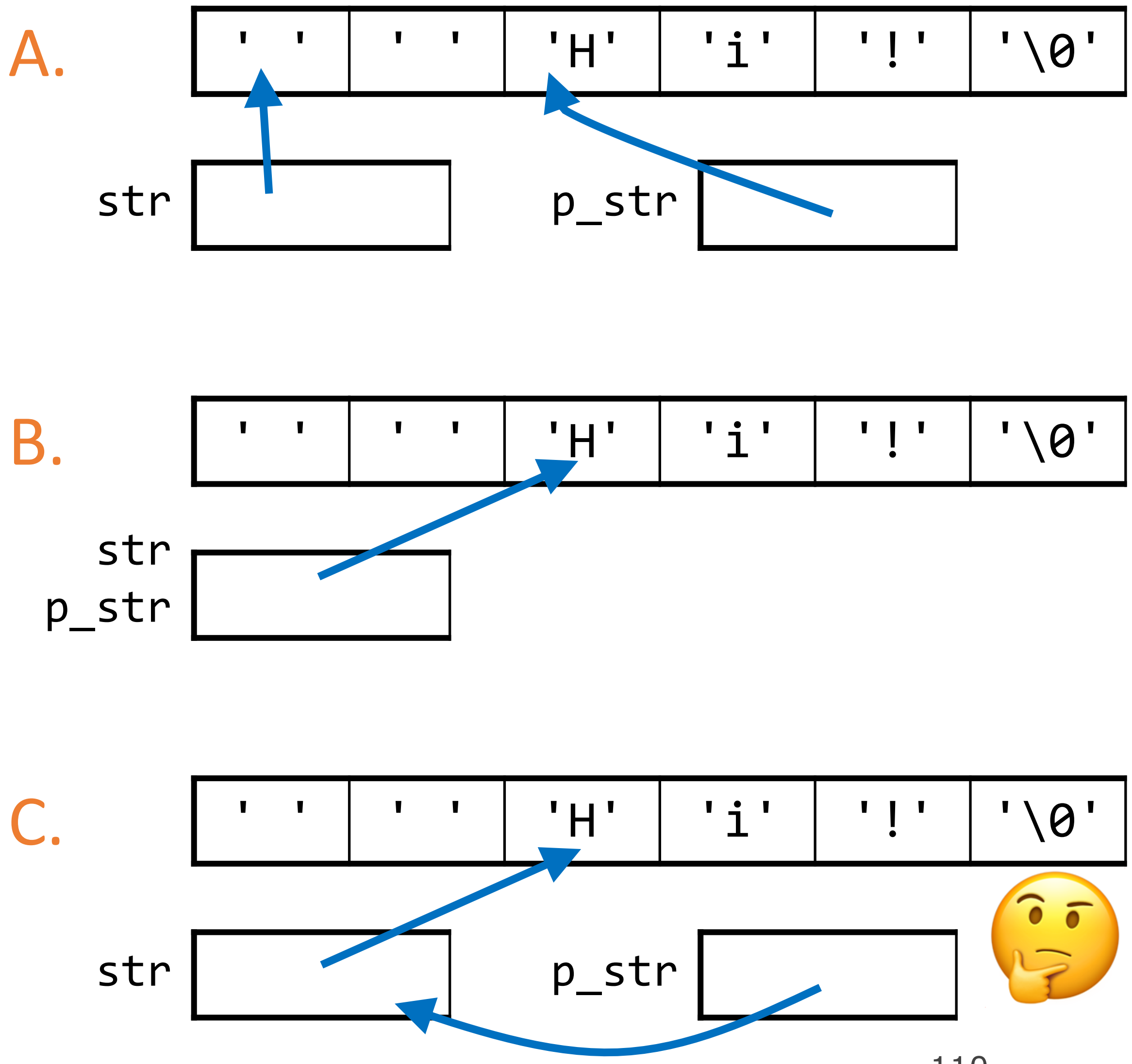
Increment value stored at memory address in cptr (increment address **pointed to**)



Skip spaces

```c
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 }
```

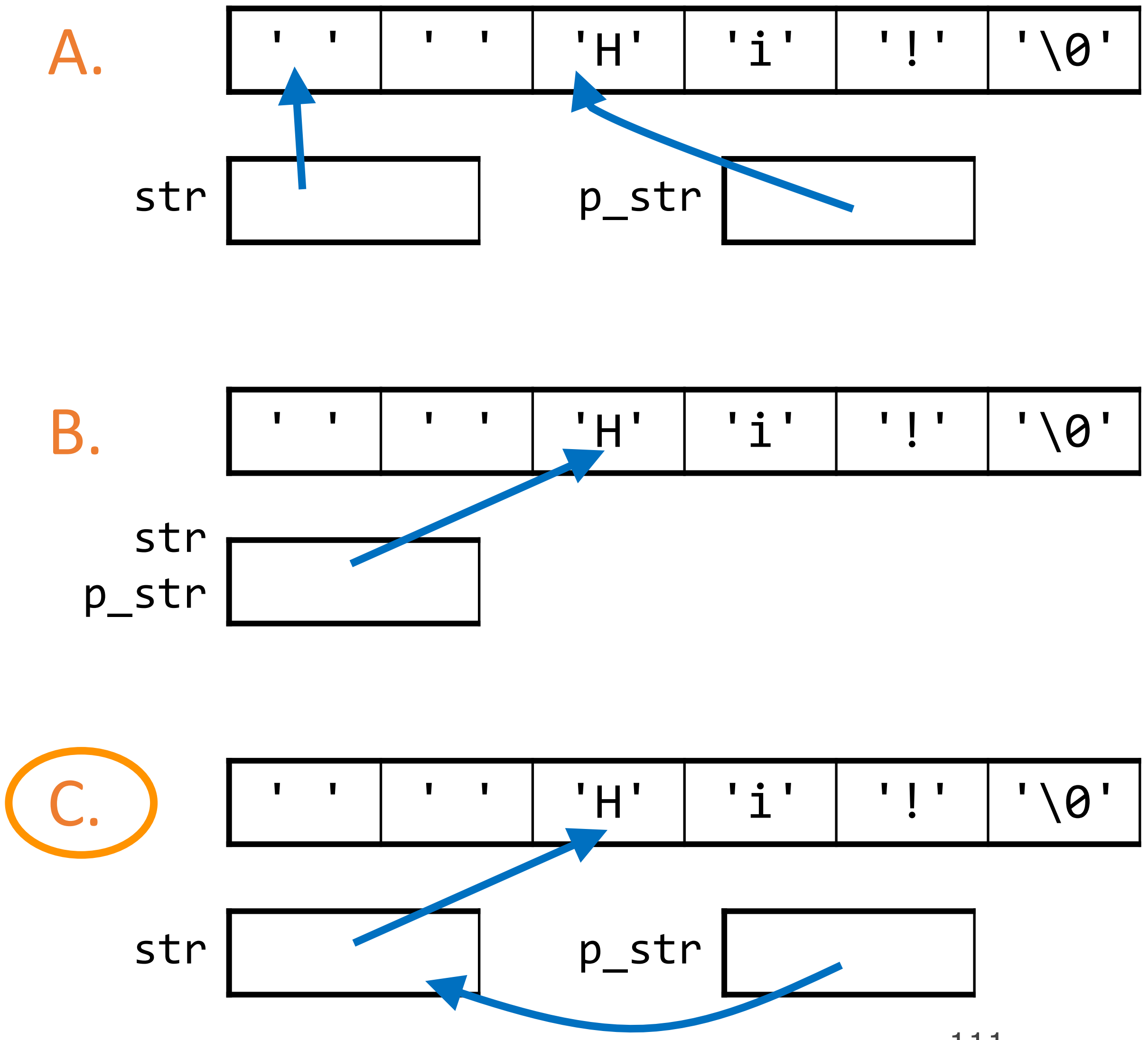
What diagram most accurately depicts program state at Line 4 (before skip_spaces returns to main)?



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`)?



const vs #define

```
#define THIRD_BIT 1 << 3
```

#define is a hard-coded substitution that gcc will make when compiling your code.

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

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

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

Const signals that this variable (in this scope) should not be modified.

- In CS107, you often won't have to declare const variables, but you will be provided parameters or use functions that have it
- Const directly modifies the adjacent keyword

(Slide 86)

const

```
1   char buf[6];
2   strcpy(buf, "Hello");
3   const char *str = buf;
4   str[0] = 'M';
5   str = "Mello";
6   buf[0] = 'M';
```

Which lines (if any) above will cause an error due to violating const? Remember that const char * means that the characters at the location it stores cannot be changed.

const

```
1 char buf[6];
2 strcpy(buf, "Hello");
3 const char *str = buf;
4 str[0] = 'M';
5 str = "Mello";
6 buf[0] = 'M';
```

Line 1 makes a typical modifiable character array of 6 characters.

Which lines (if any) above will cause an error due to violating const?

Remember that const char * means that the characters at the location it stores cannot be changed.

const

```
1 char buf[6];
2 strcpy(buf, "Hello");
3 const char *str = buf;
4 str[0] = 'M';
5 str = "Mello";
6 buf[0] = 'M';
```

Line 2 copies characters into this modifiable character array.

Which lines (if any) above will cause an error due to violating const? Remember that const char * means that the characters at the location it stores cannot be changed.

const

```
1   char buf[6];
2   strcpy(buf, "Hello");
3   const char *str = buf;
4   str[0] = 'M';
5   str = "Mello";
6   buf[0] = 'M';
```

Line 3 makes a const pointer that points to the first element of buf. We cannot use str to change the characters it points to because it is const.

Which lines (if any) above will cause an error due to violating const?

Remember that const char * means that the characters at the location it stores cannot be changed.

const

```
1  char buf[6];
2  strcpy(buf, "Hello");
3  const char *str = buf;
4  str[0] = 'M';
5  str = "Mello";
6  buf[0] = 'M';
```

Line 4 is not allowed – it attempts to use a const pointer to characters to modify those characters.

Which lines (if any) above will cause an error due to violating const?
Remember that const char * means that the characters at the location it stores cannot be changed.

const

```
1 char buf[6];
2 strcpy(buf, "Hello");
3 const char *str = buf;
4 str[0] = 'M';
5 str = "Mello";
6 buf[0] = 'M';
```

Line 5 is ok – str’s type means that while you cannot change the characters at which it points, you can change str itself to point somewhere else. **str** is not const – its characters are.

Which lines (if any) above will cause an error due to violating const?

Remember that const char * means that the characters at the location it stores cannot be changed.

const

```
1  char buf[6];
2  strcpy(buf, "Hello");
3  const char *str = buf;
4  str[0] = 'M';
5  str = "Mello";
6  buf[0] = 'M';
```

✅ 1, ✅ 2, ✅ 3, ❌ 4, ✅ 5, ✅ 6

Line 6 is ok – **buf** is a modifiable char array, and we can use it to change its characters. Declaring str as const doesn't mean that place in memory is not modifiable at all – it just means that you cannot modify it using **str**.

Which lines (if any) above will cause an error due to violating const?

Remember that const char * means that the characters at the location it stores cannot be changed.