

CS107, Lecture 9

Pointers and Arrays

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



masks recommended

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

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Announcement: CS198 Section Leading

[CS198 Slides](#)

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

CS107 Topic 3

How can we effectively manage all types of memory in our programs?

Why is answering this question important?

- Shows us how we can pass around data efficiently with pointers (this time)
- Introduces us to the heap and allocating memory that we manually manage (next time)
- Helps us better understand use-after-free vulnerabilities, a common bug (next week)

assign3: implement a function using resizable arrays to read lines of any length from a file and write 2 programs using that function to print the last N lines of a file and print just the unique lines of a file. These programs emulate the **tail** and **uniq** Unix commands!

Learning Goals

- Learn about pointers and how they help us access data without making copies
- Understand arrays and how they relate to pointers
- Get more practice using memory diagrams to understand code behavior

Lecture Plan

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

```
cp -r /afs/ir/class/cs107/lecture-code/lect9 .
```

Lecture Plan

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

```
cp -r /afs/ir/class/cs107/lecture-code/lect9 .
```

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.

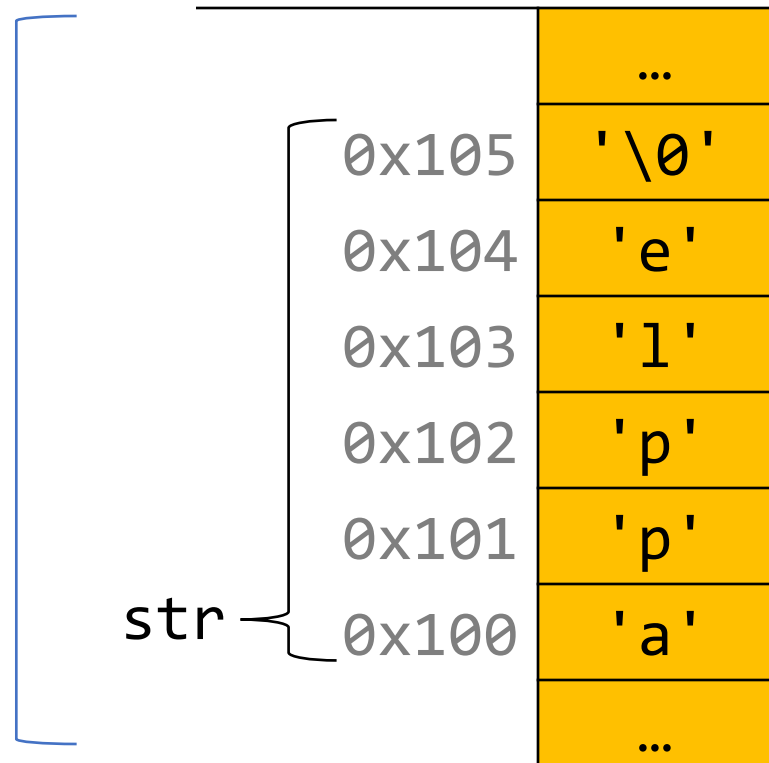
char[]

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");  
    ...  
}
```

main()

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

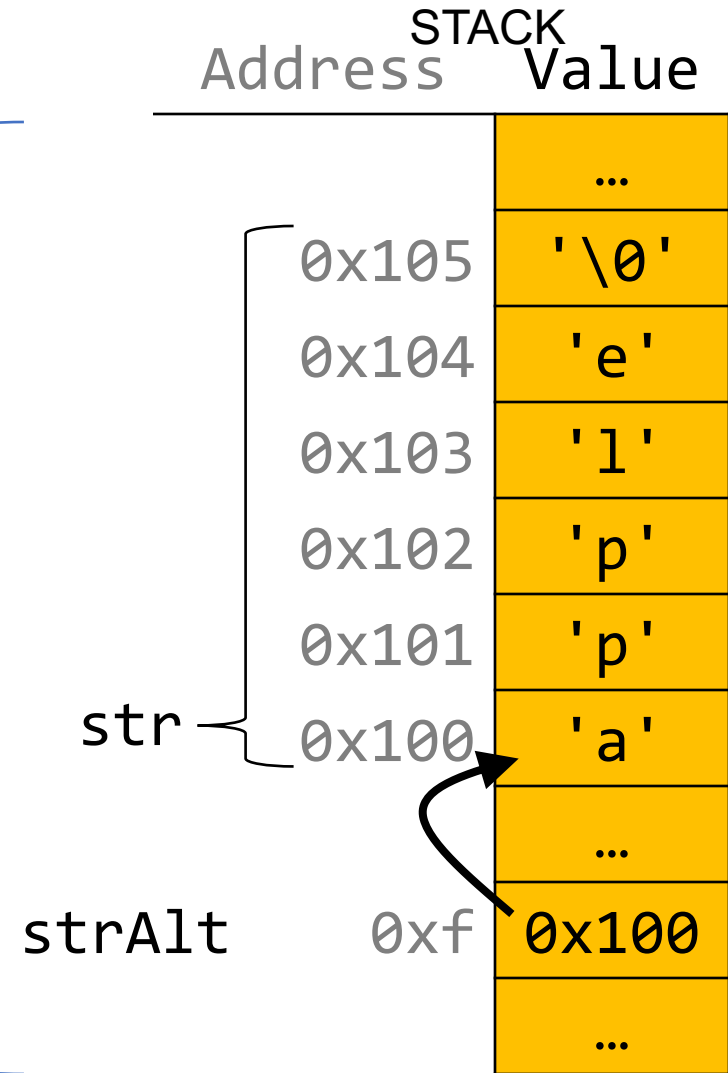


char *

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;  
    ...  
}
```

main()

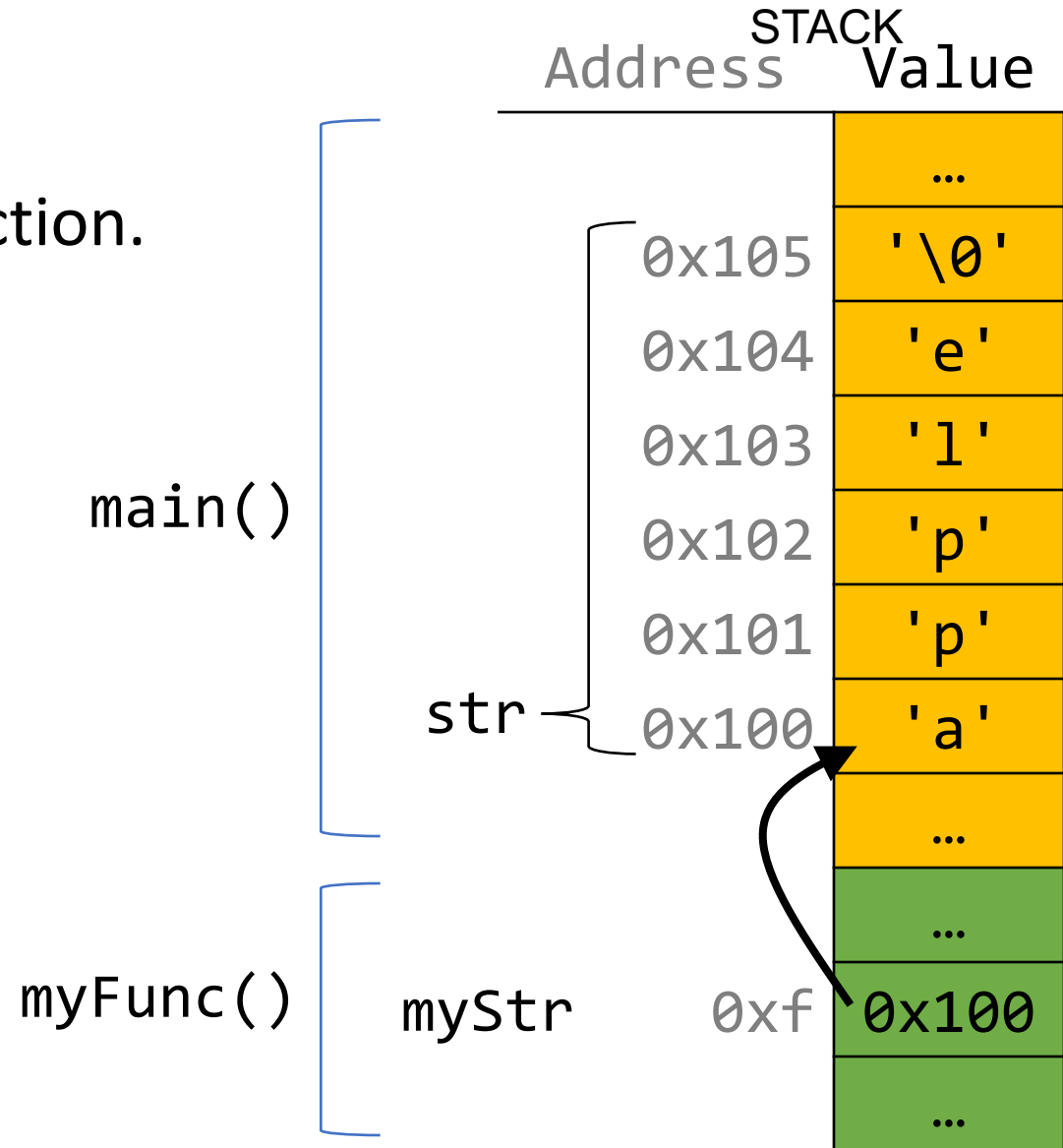


Strings as Parameters

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) {  
    ...  
}
```

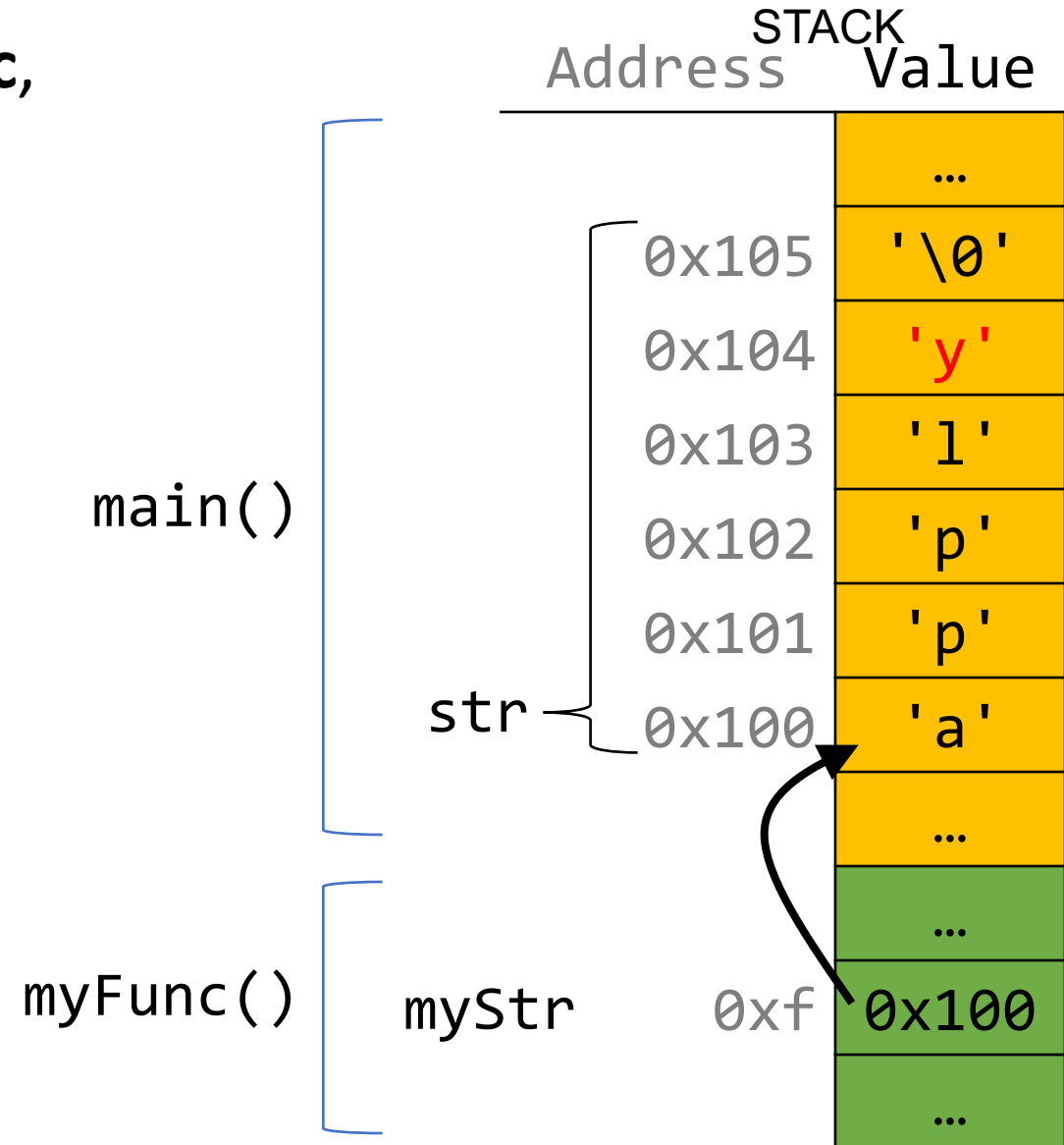
```
int main(int argc, char *argv[]) {  
    char str[6];  
    strcpy(str, "apple");  
    myFunc(str);  
    ...  
}
```



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. 0xffff0  
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;  
    ...  
}
```

main()

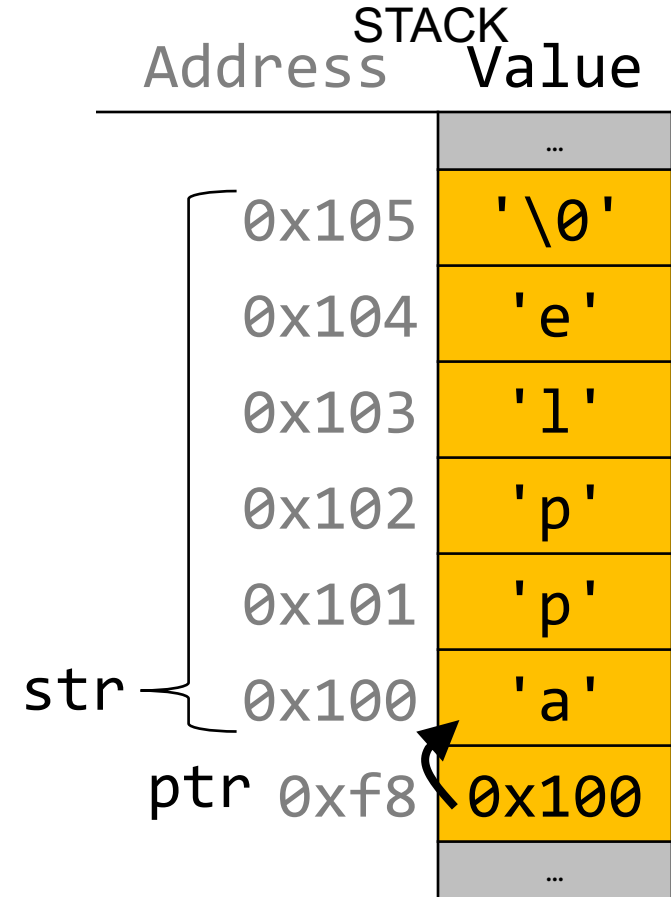
STACK	
Address	Value
	...
0x105	'\0'
0x104	'e'
0x103	'l'
0x102	'p'
0x101	'p'
str { 0x100	'a'
ptr 0xf8	0x100
	...

Arrays and Pointers

We can also make a pointer equal to an array;
it will point to the first element in that array.

```
int main(int argc, char *argv[]) {  
    char str[6];  
    strcpy(str, "apple");  
    char *ptr = str;  
  
    // equivalent  
    char *ptr = &str[0];  
  
    // confusingly equivalent, avoid  
    char *ptr = &str;  
    ...  
}
```

main()



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!
```

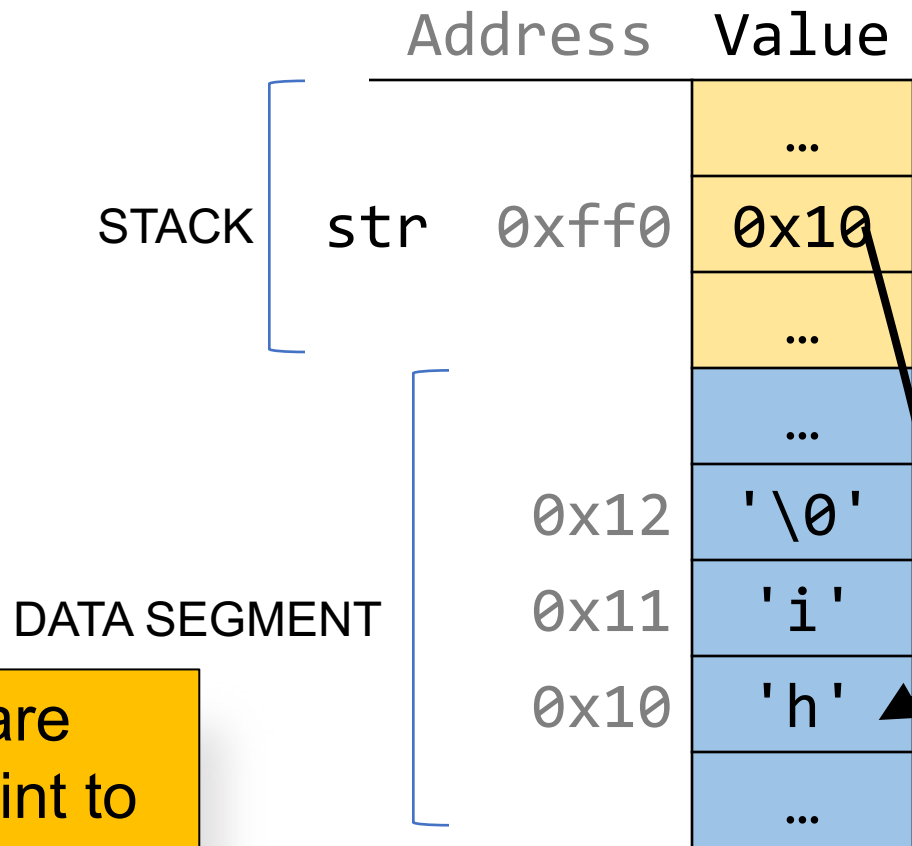
Read-only Strings

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

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

```
cp -r /afs/ir/class/cs107/lecture-code/lect9 .
```

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);  
}
```

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.

```
int main(int argc, char *argv[]) {  
    int num = 3;  
    printSquare(num); // should print 9  
}
```

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);  
    }  
}
```

We are modifying a specific instance of the letter, so we pass the *location* of the letter we would like to modify.

```
int main(int argc, char *argv[]) {  
    char ch = 'g';  
    flipCase(&ch);  
    printf("%c", ch);    // want this to print 'G'
```

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"  
}
```

Respond with your thoughts
on PollEv: pollev.com/cs107 or
text CS107 to 22333 once to join.



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;  
}
```

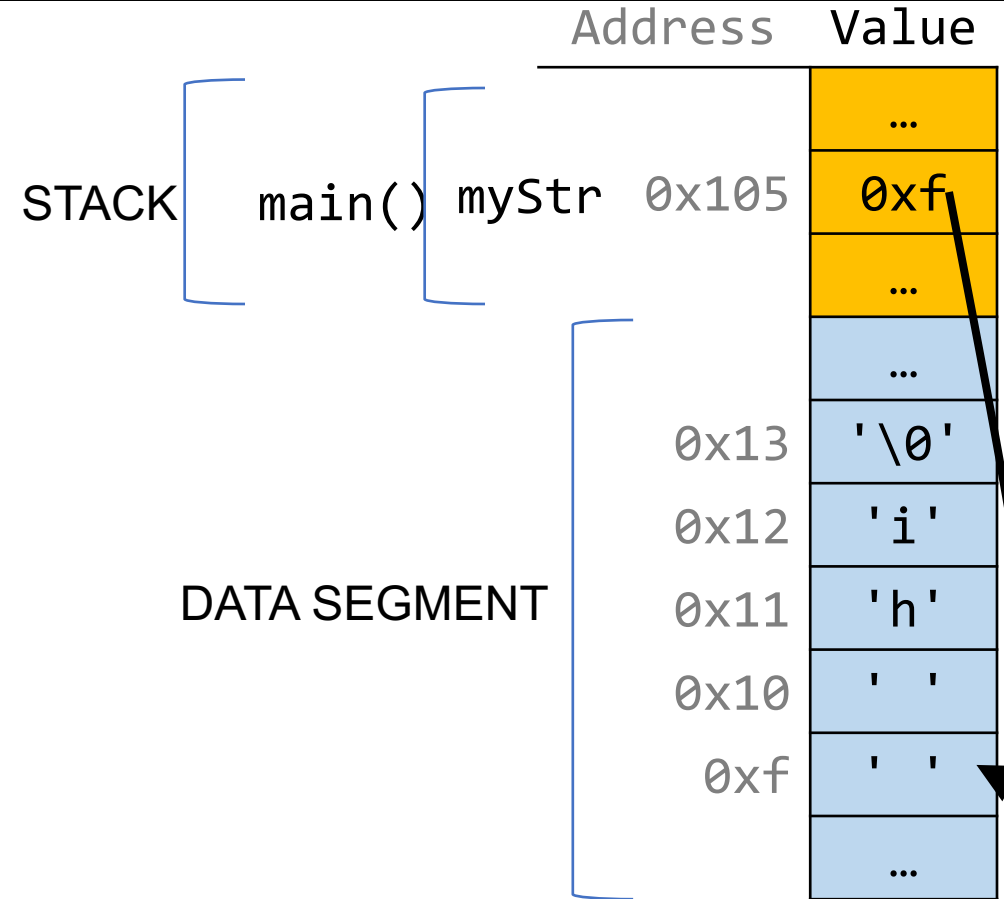
```
int main(int argc, char *argv[]) {  
    char *myStr = " hi";  
    skipSpaces(&myStr);  
    printf("%s\n", myStr);    // hi  
    return 0;  
}
```

STACK [main() [

Address	Value
	...
	...

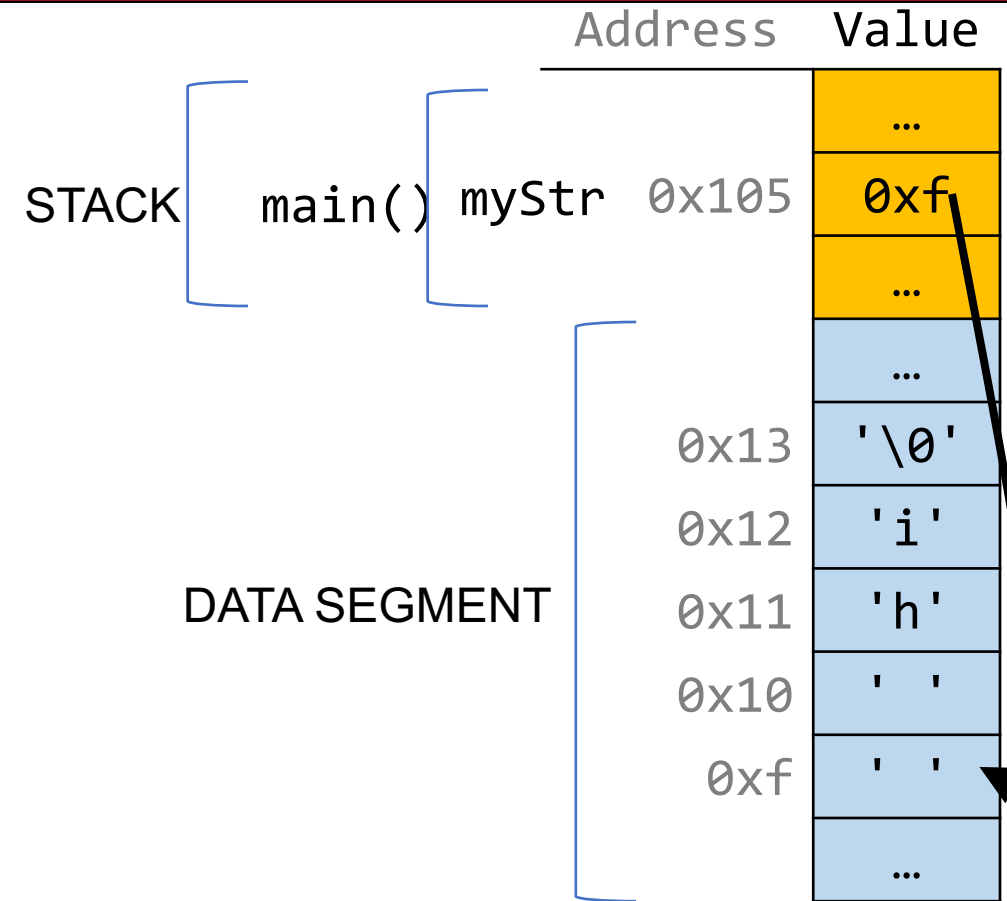
Pointers to Strings

```
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;  
}
```



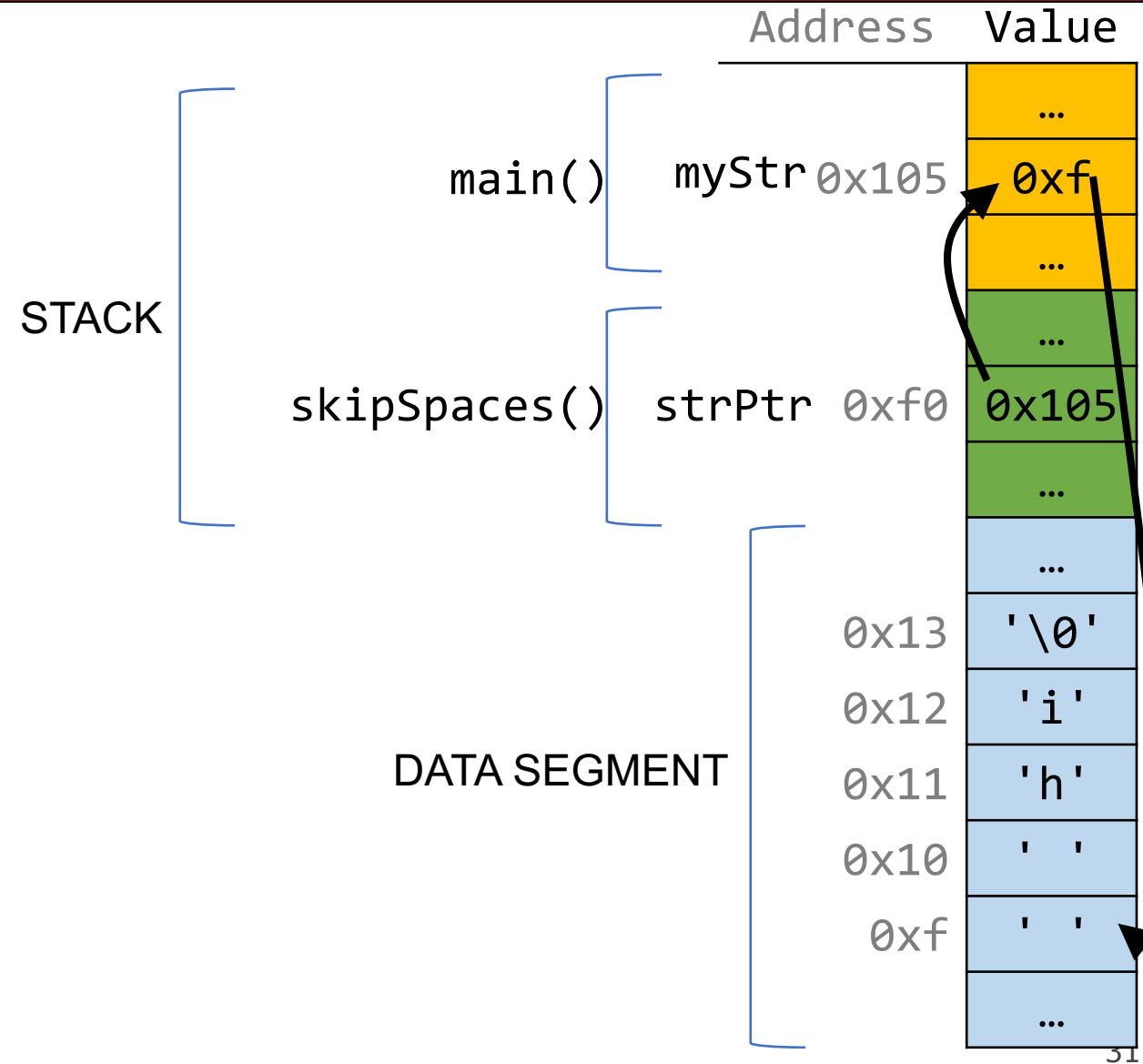
Pointers to Strings

```
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;  
}
```



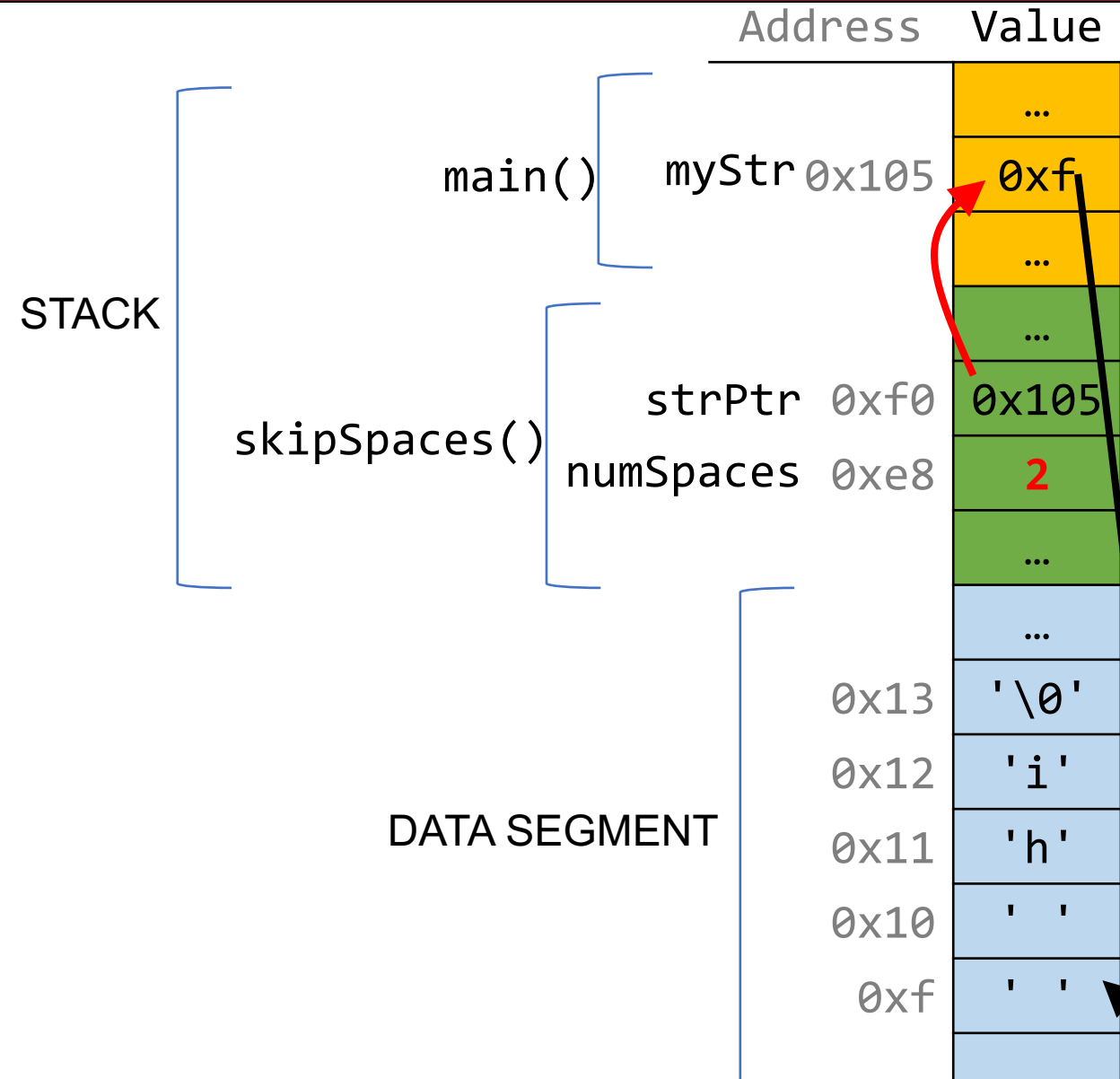
Pointers to Strings

```
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;  
}
```



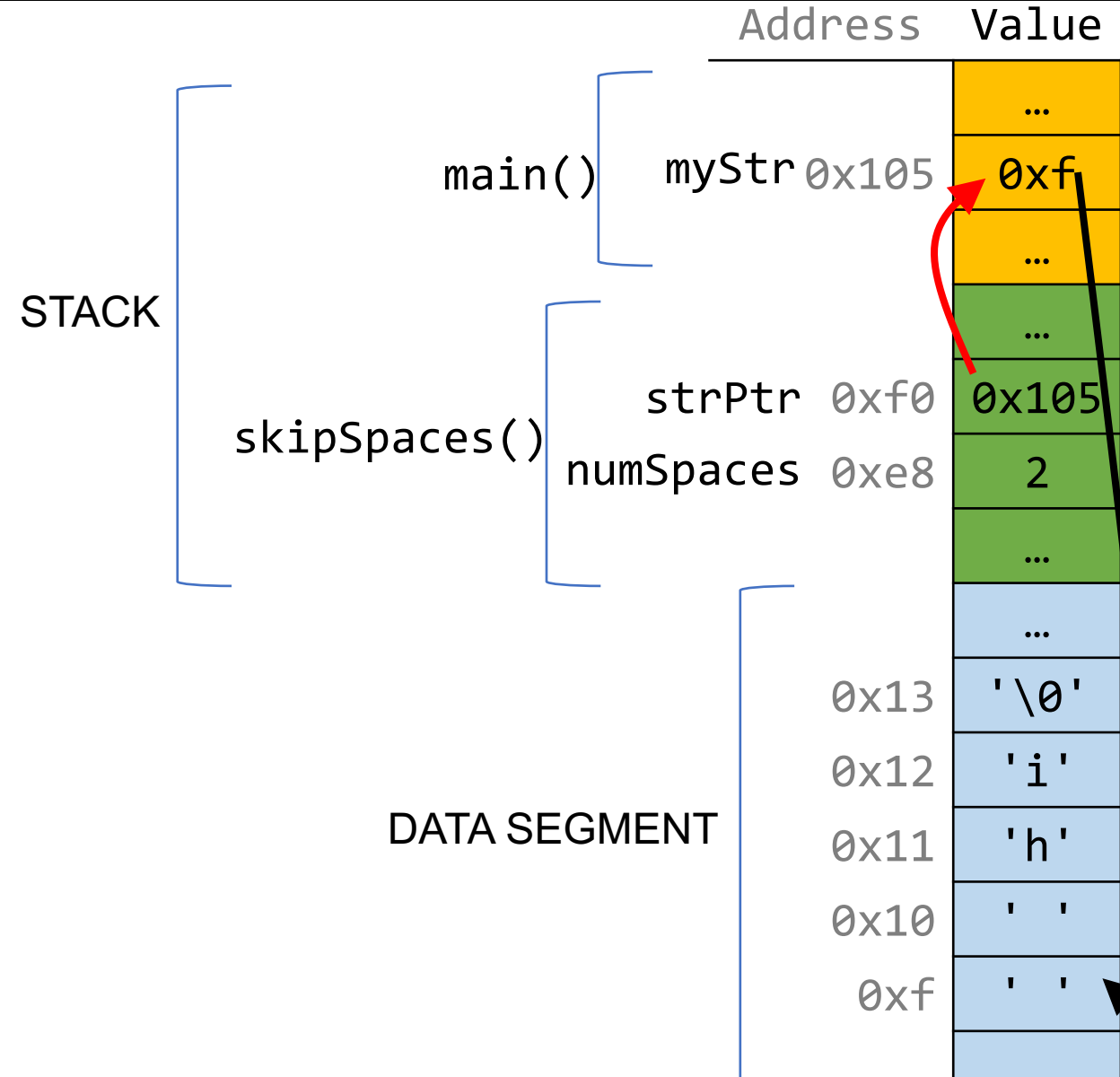
Pointers to Strings

```
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;  
}
```



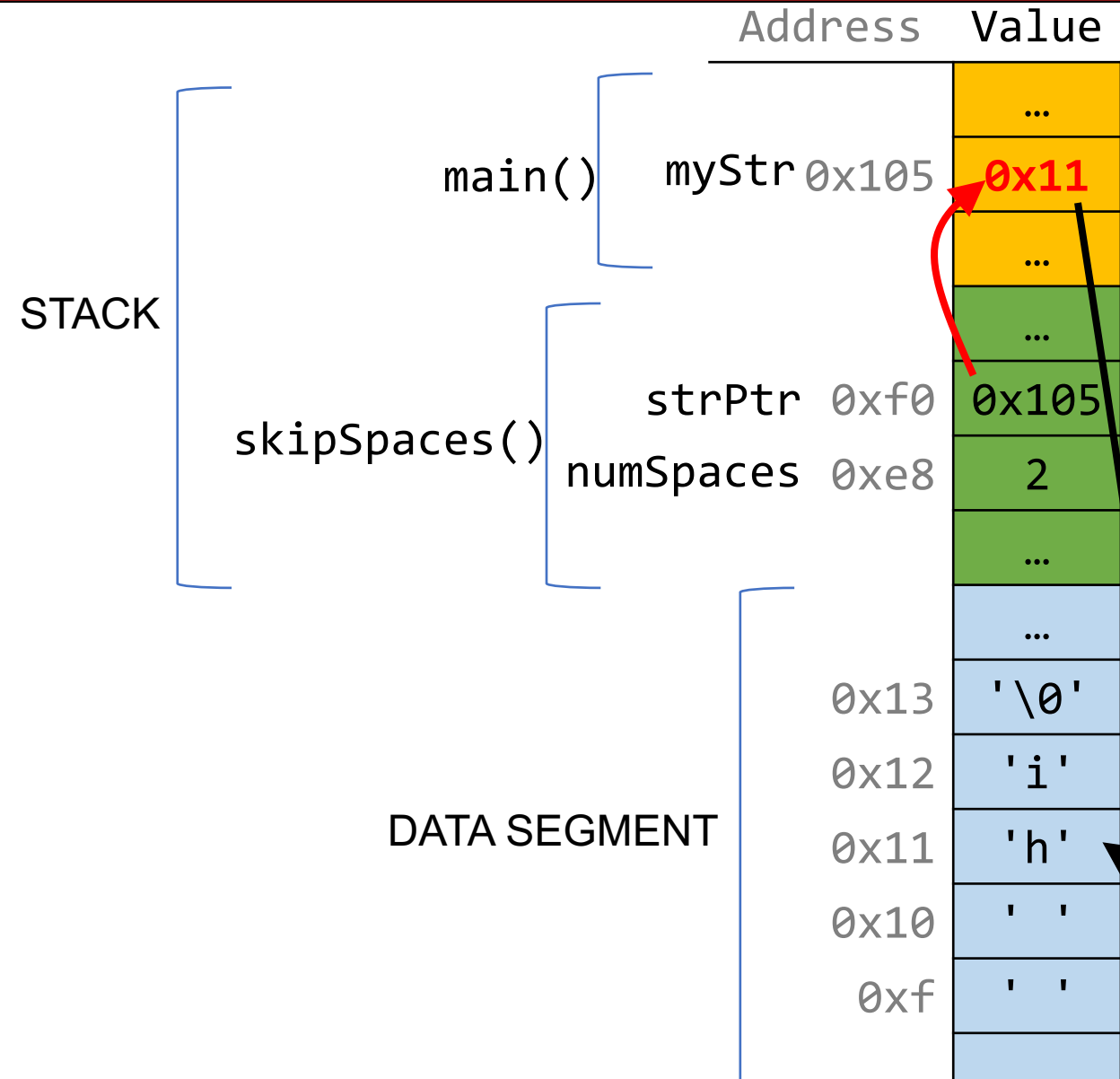
Pointers to Strings

```
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;  
}
```



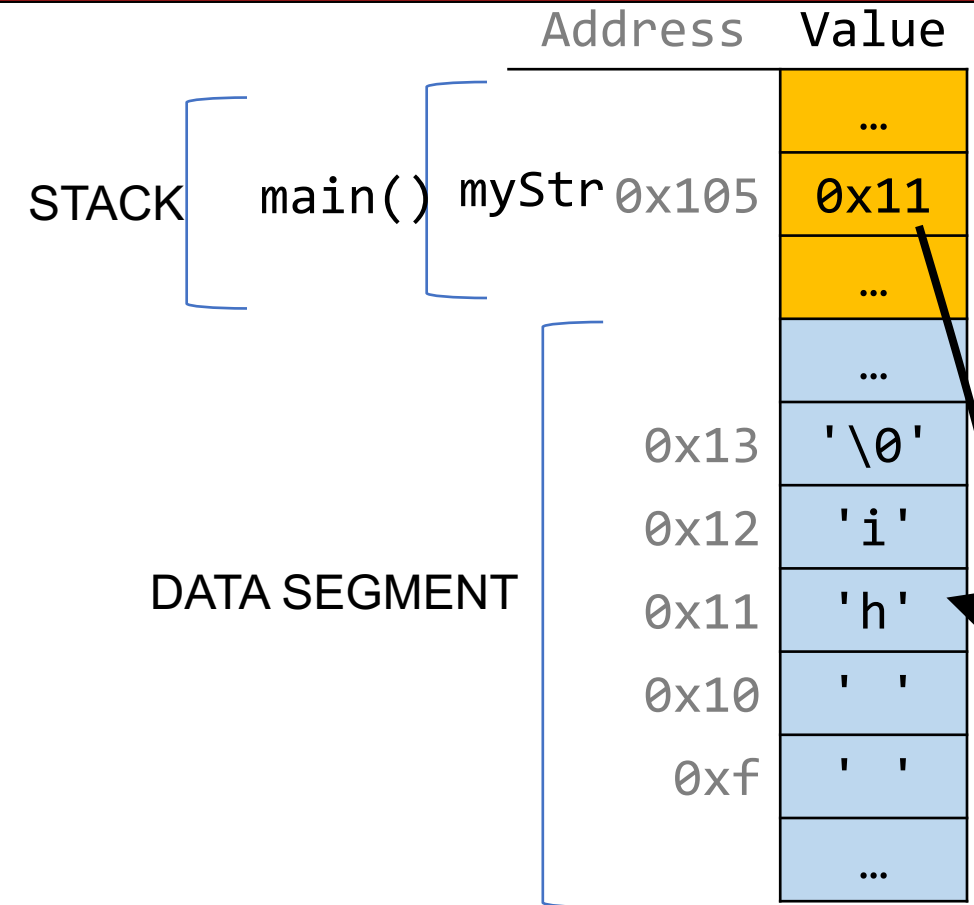
Pointers to Strings

```
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

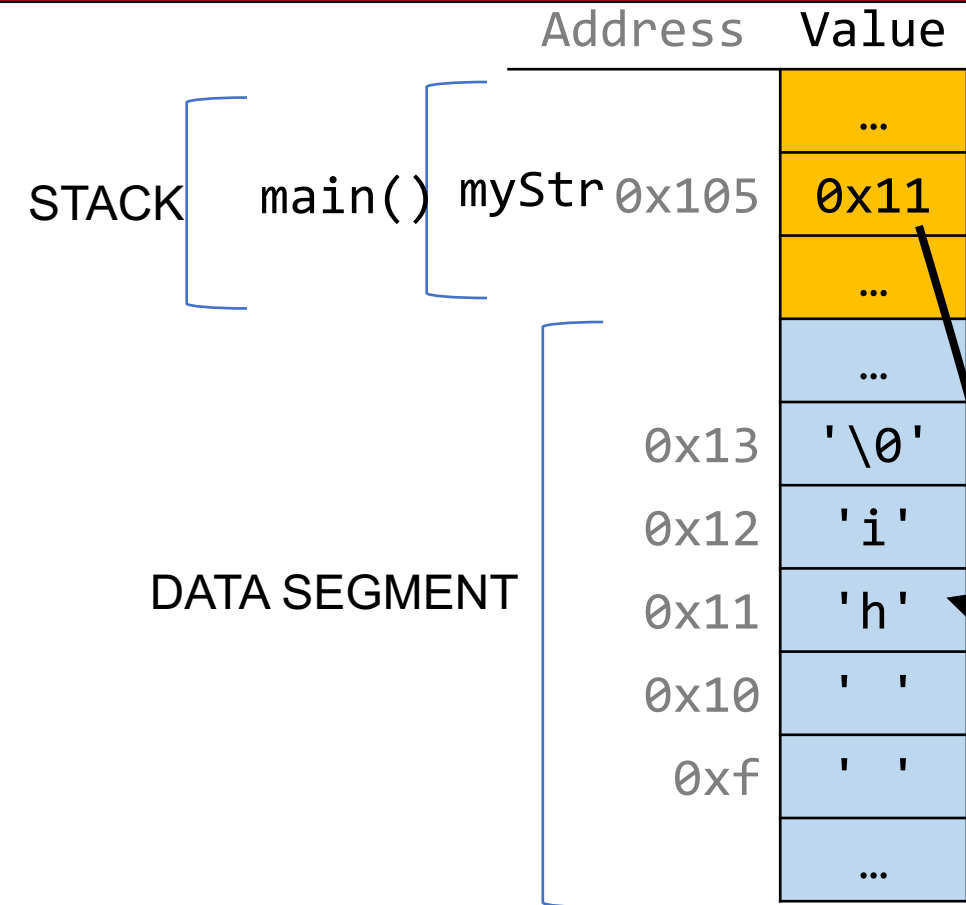
```
void skipSpaces(char **strPtr) {  
    int numSpaces = strspn(*strPtr, " ");  
    *strPtr += numSpaces;  
}  
  
int main(int argc, char *argv[]) {  
    char *myStr = " hi";  
    skipSpaces(&myStr);  
    printf("%s\n", myStr);           // hi  
    return 0;  
}
```



Pointers to Strings

```
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;  
}
```

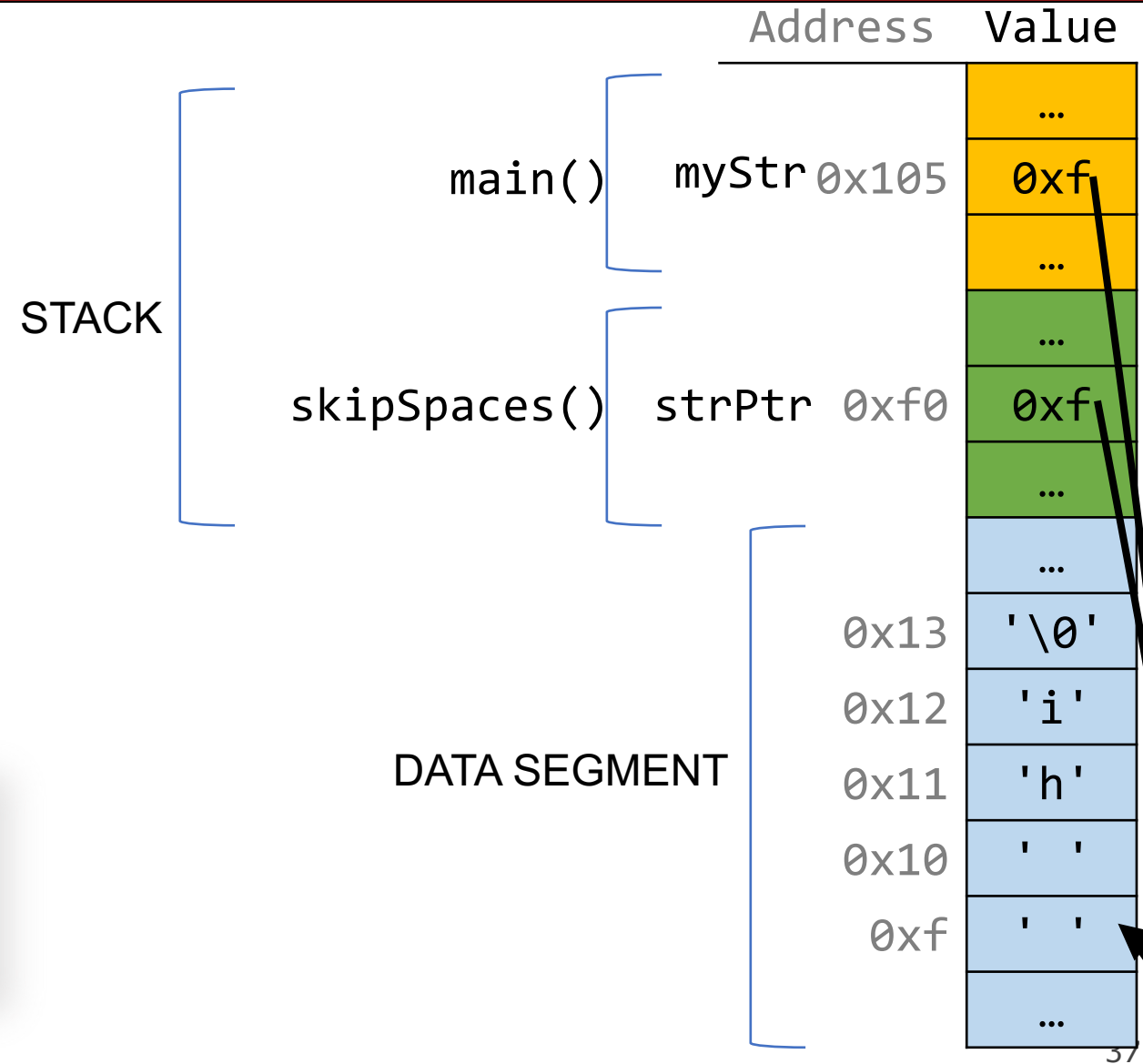
Weird thought – **0x11** is a string.



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
- Double Pointers
-

Lecture 9 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.

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 `eu1o3`

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

Line B: Segmentation fault
(string literal)

3. Bonus: Tricky addresses

```
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
11     char *ptr2 = &buf;
12     printf("ptr2's value:      %s\n", ptr2);
13 }
```

What is stored in each variable?



3. Bonus: Tricky addresses

```
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
11     char *ptr2 = &buf;
12     printf("ptr2's value:      %s\n", ptr2);
13 }
```

	0x28	0x29	0x2a	0x2b	0x2c	0x2d
buf	'L'	'o'	'c'	'a'	'l'	'\0'

ptr1 0x10

double_ptr 0x18

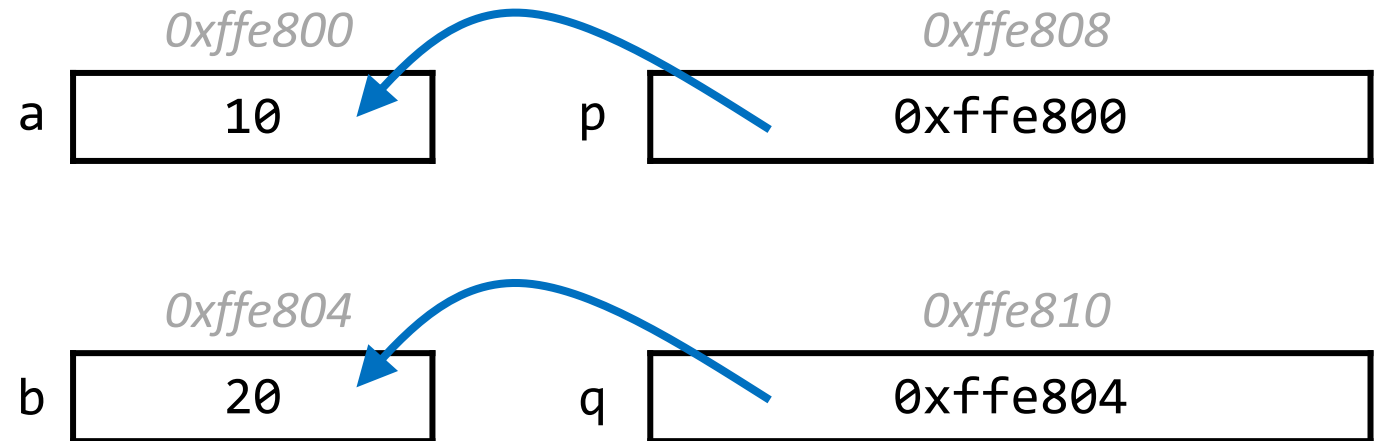
ptr2 0x20

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 }
```

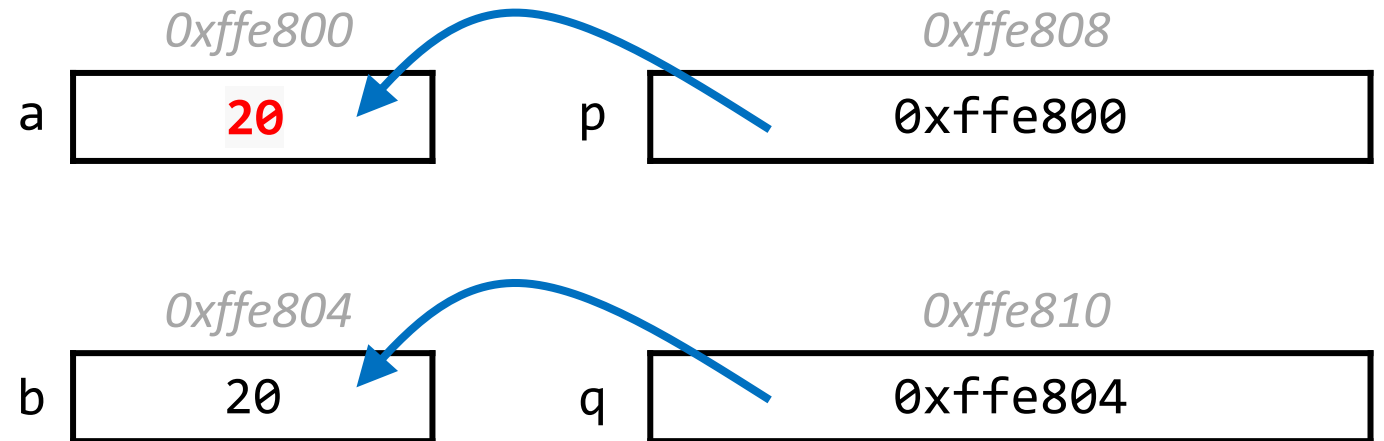
- Lines 2-5: Draw a diagram.
- Line 7: Update your diagram.
- Line 8: Update your diagram.



Pen and paper: A * Wars Story

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

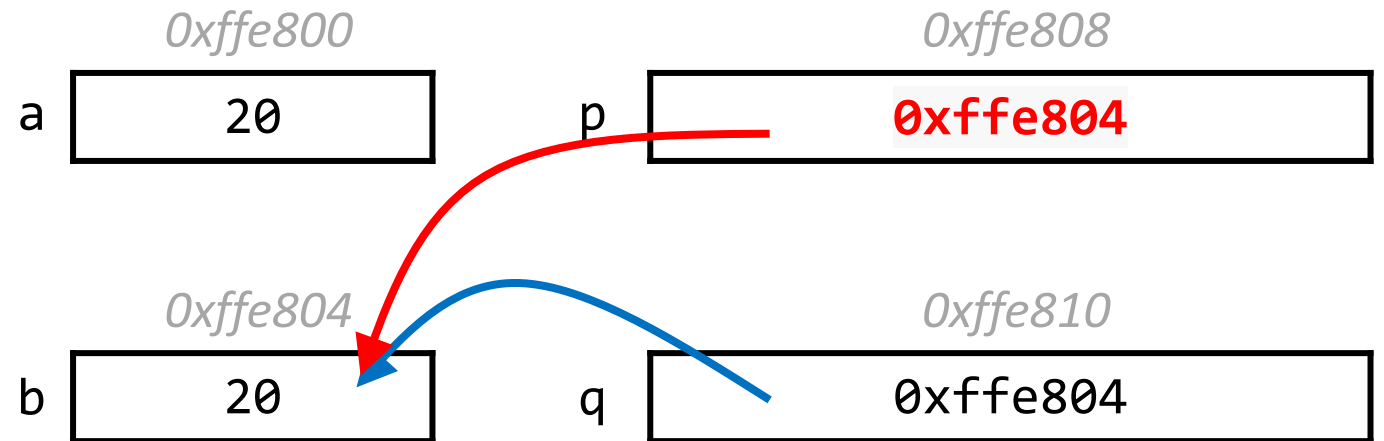
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Pen and paper: A * Wars Story

```
1 void binky() {  
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4     int *p = &a;  
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6  
7     *p = *q;  
8     p = q;  
9 }
```

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



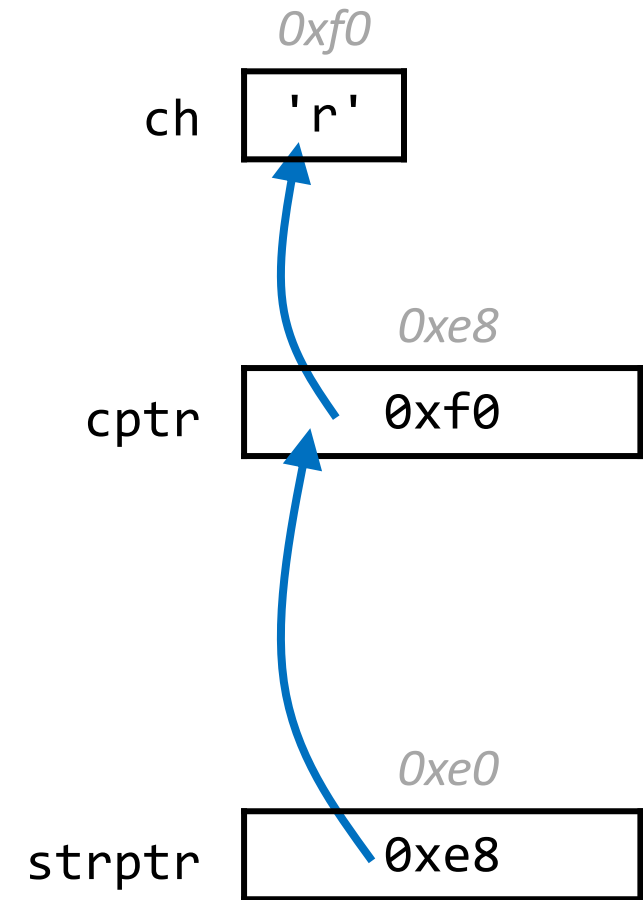
* Wars: Episode I (of 2)

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.

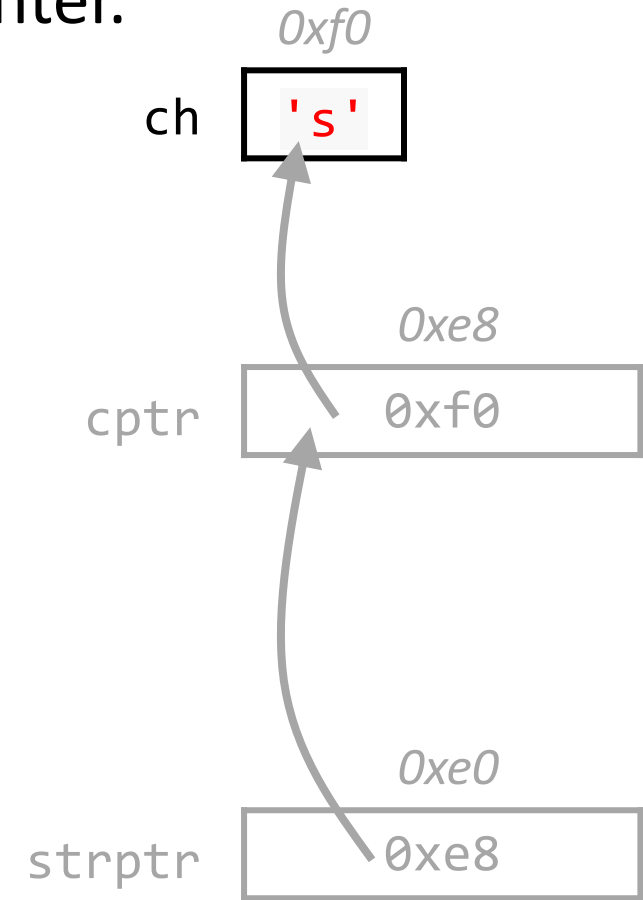
```
char ch = 'r';
```

```
ch = ch + 1;
```

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

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

Increment value stored in ch



* Wars: Episode II (of 2)

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

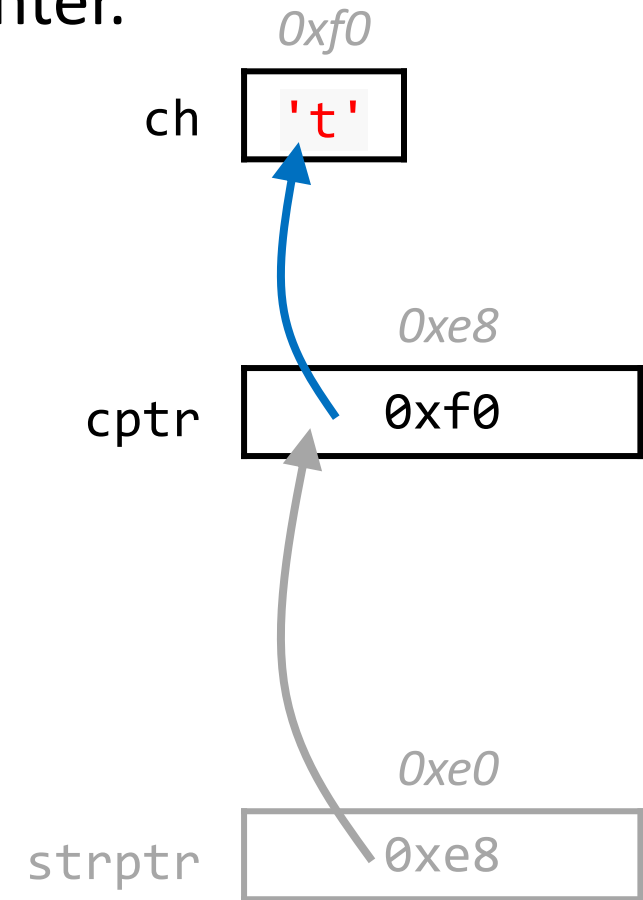
```
char ch = 'r';  
ch = ch + 1;
```

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;
```

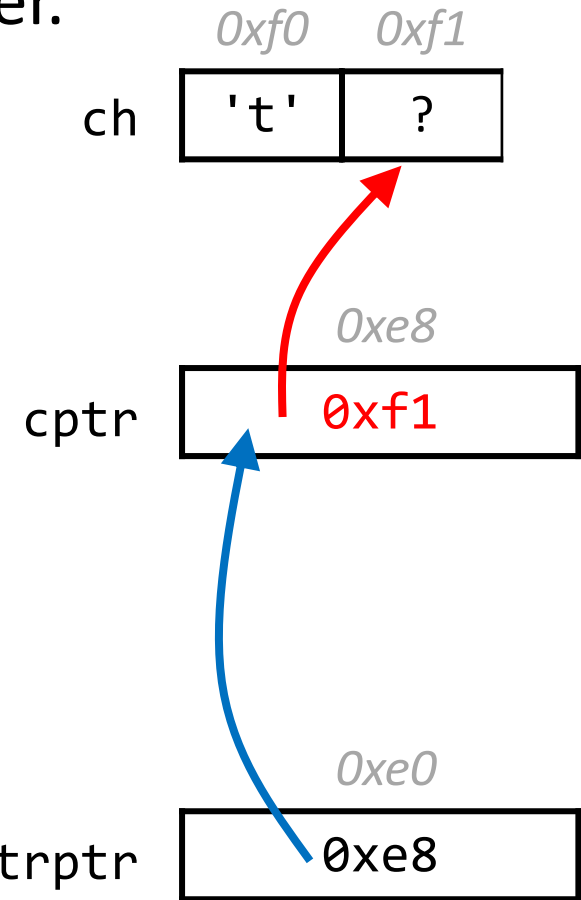
Increment value stored in ch

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

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

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

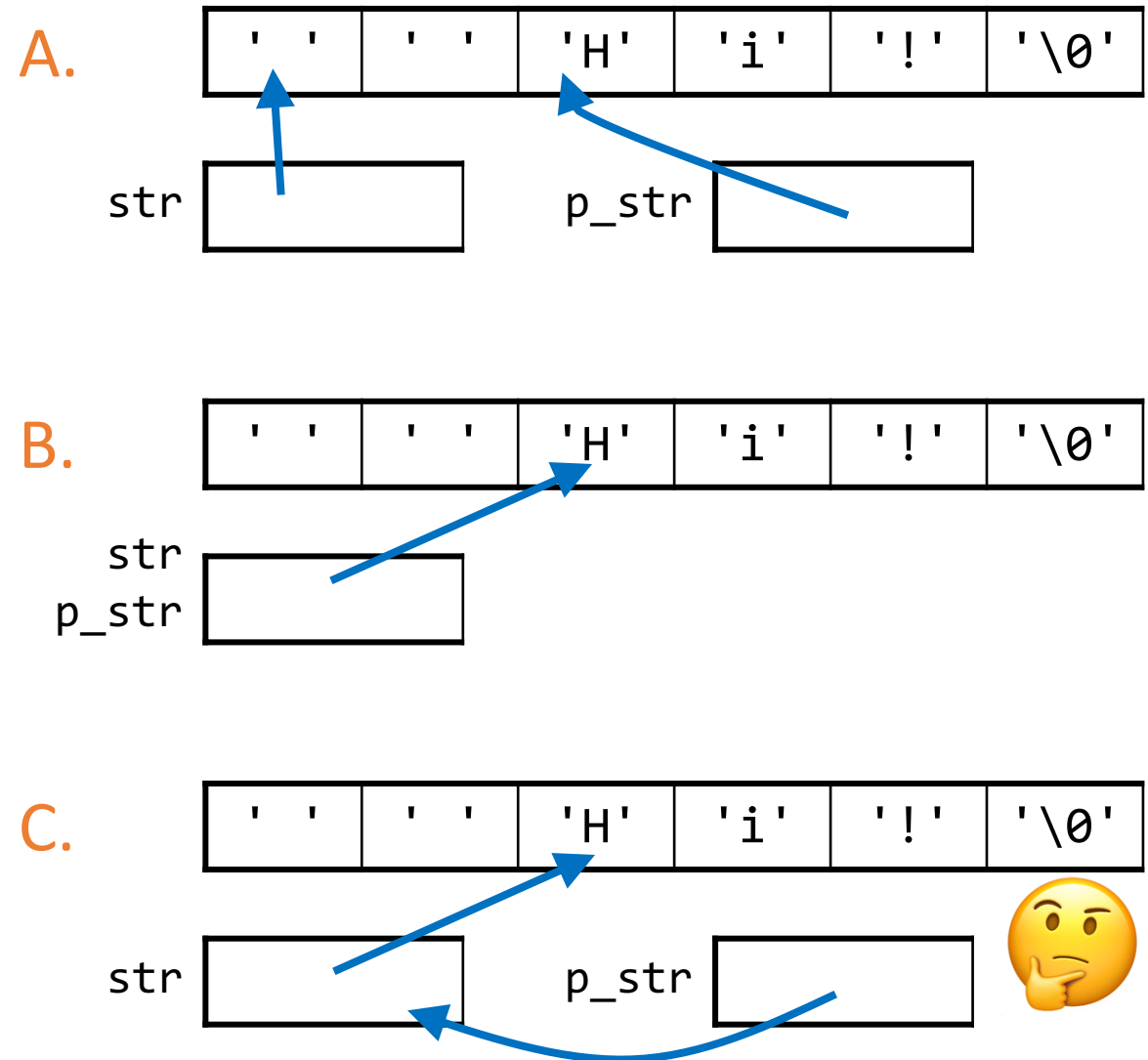
Increment value stored at
memory address in cptr
(increment address **pointed to**)



Skip spaces

```
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)?

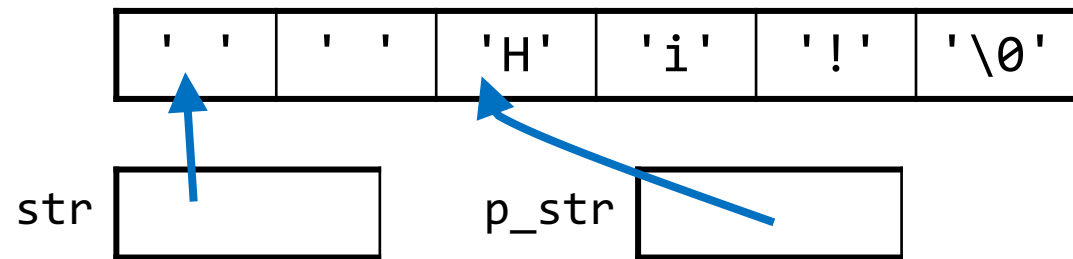


Skip spaces

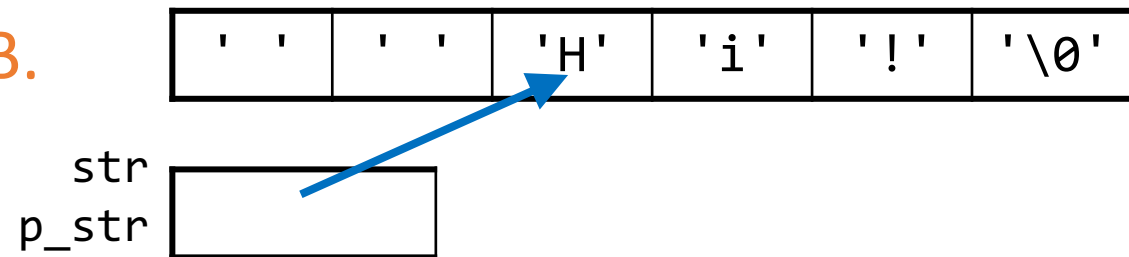
```
1 void skip_spaces(char **p_str) {  
2     int num = strspn(*p_str, " ");  
3     *p_str = *p_str + num;  
4 }  
5 int main(int argc, char *argv[]){  
6     char *str = "  Hi!";  
7     skip_spaces(&str);  
8     printf("%s", str); // "Hi!"  
9     return 0;  
10 }
```

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

A.



B.



C.

