CS107, Lecture 9
Pointers and Arrays

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

This document is copyright (C) Stanford Computer Science and Nick Troccoli, licensed under Creative Commons Attribution 2.5 License. All rights reserved.
Based on slides created by Cynthia Lee, Chris Gregg, Jerry Cain, Lisa Yan and others.
NOTICE RE UPLOADING TO WEBSITES: This content is protected and may not be shared, uploaded, or distributed. (without expressed written permission)

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

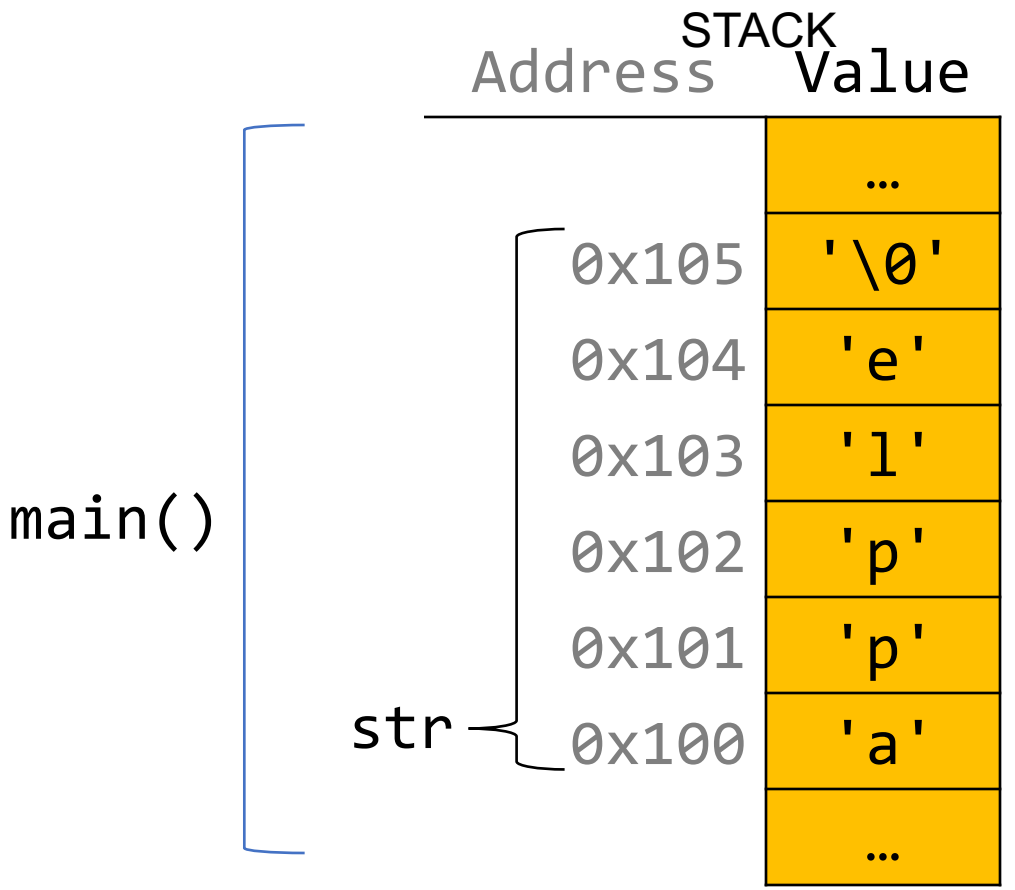
- If you are performing an operation with some input and do not care about any changes to the input, pass the data type itself.
- If you are modifying a specific instance of some value, pass the *location* of what you would like to modify and dereference that location to access what's there.
- If a function takes an address (pointer) as a parameter, it can *go to* that address if it needs the actual value.

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.

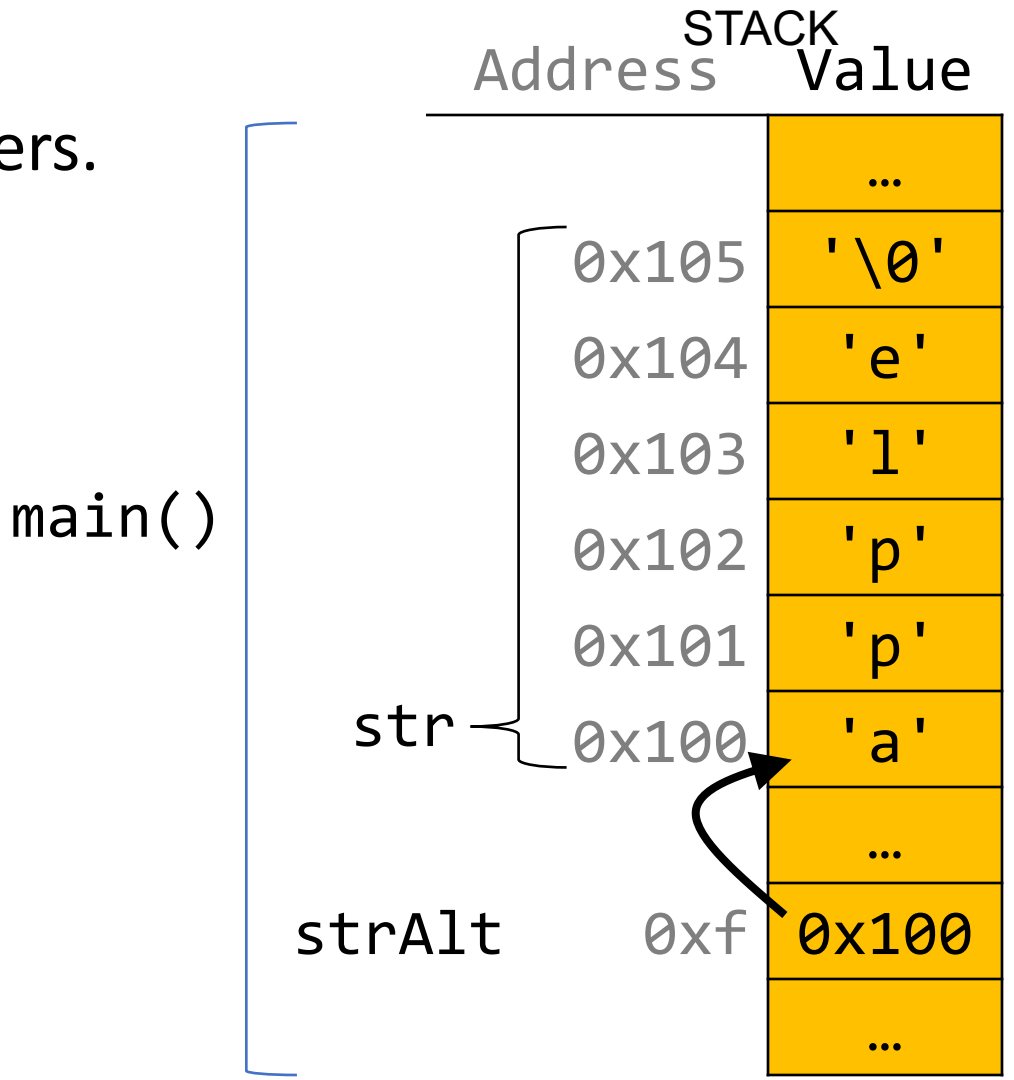
```
int main(int argc, char *argv[]) {
      char str[6];
      strcpy(str, "apple");
      ...
```



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[]**.

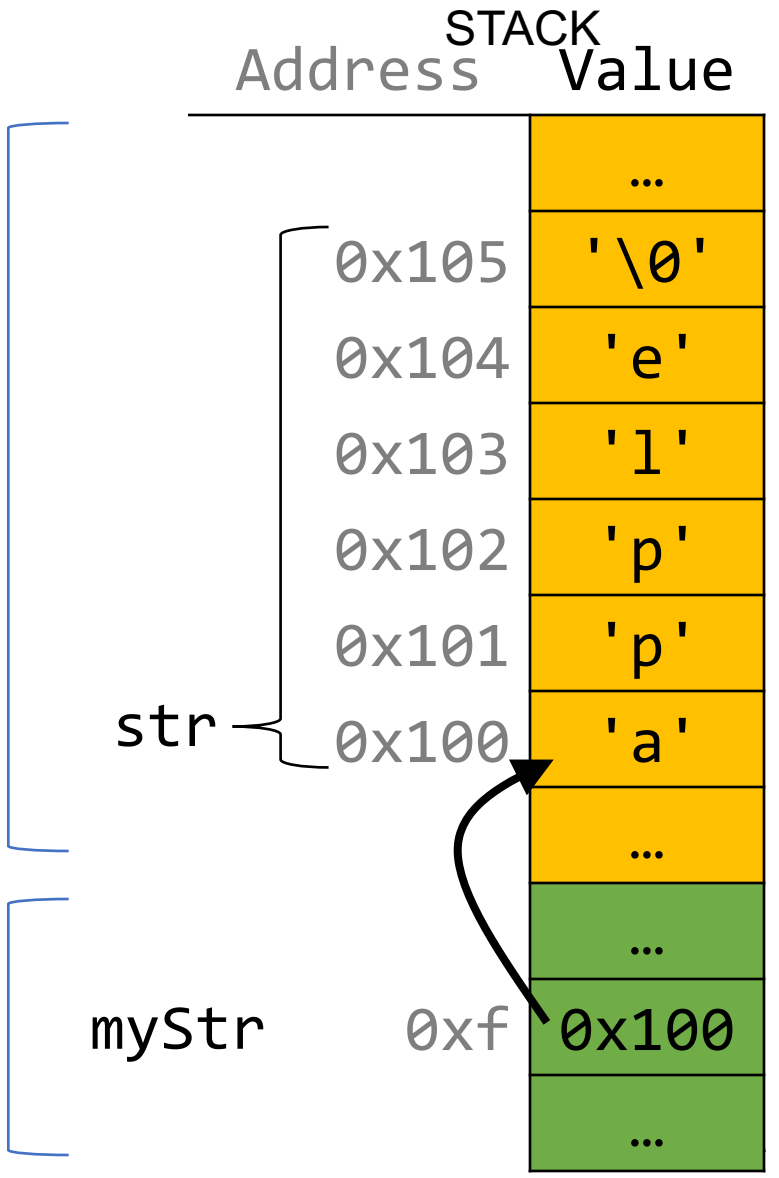
```
int main(int argc, char *argv[]) {
      char str[6];
      strcpy(str, "apple");
      char *strAlt = str;
      ...
```



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.

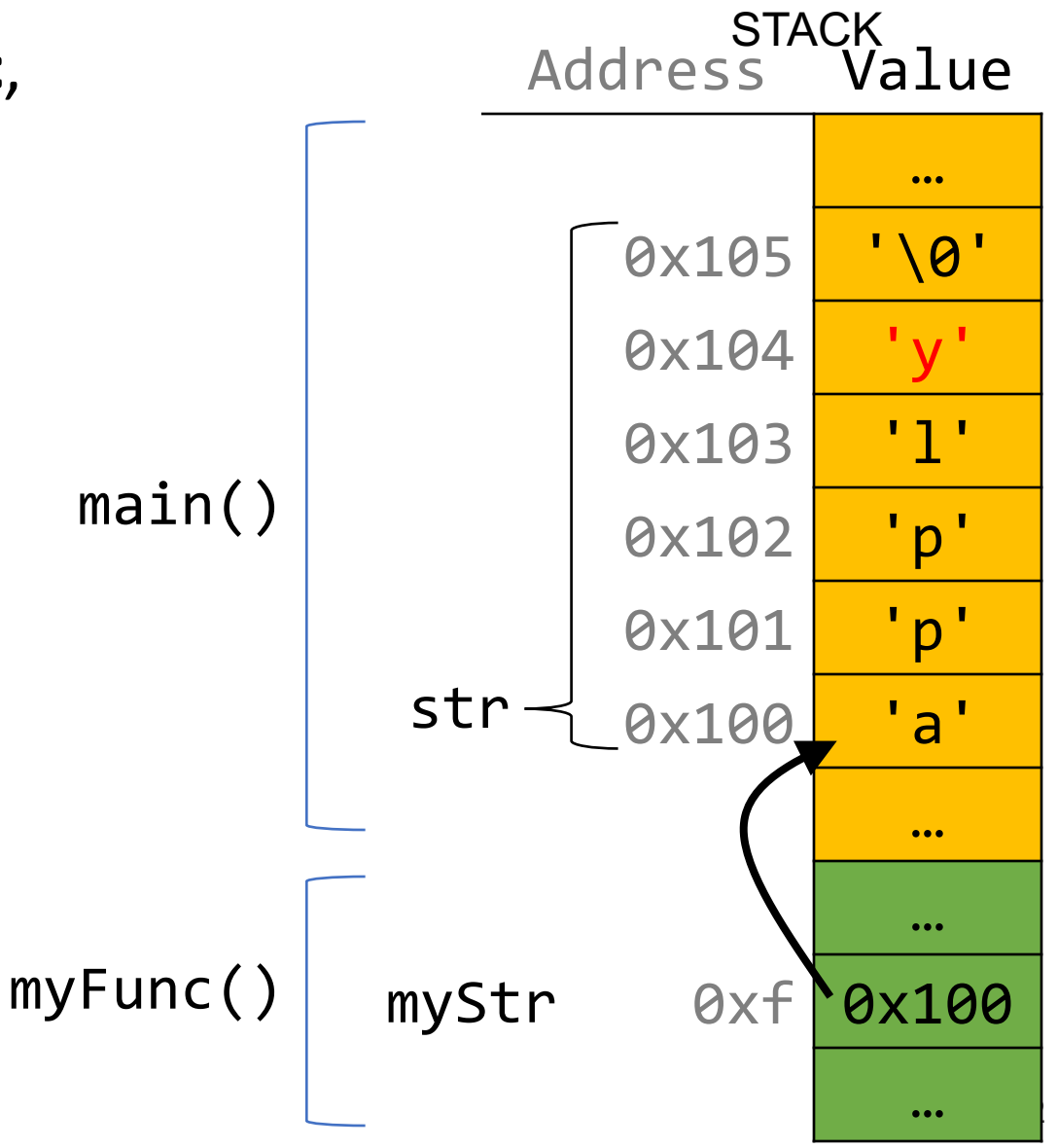
```
void myFunc(char *myStr) {
      ...
}

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 *

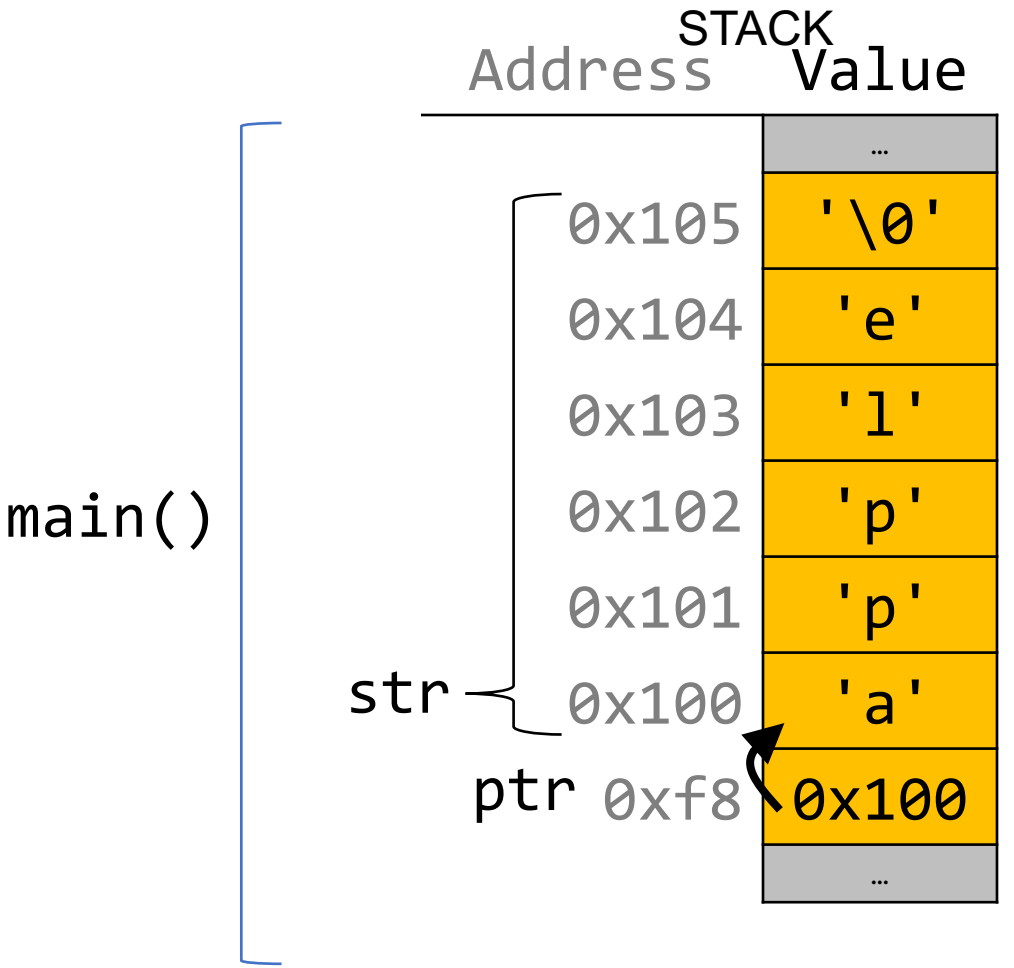
A **char** * variable refers to a single character. We can reassign an existing **char** * pointer to be equal to another **char** * pointer.

```
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.

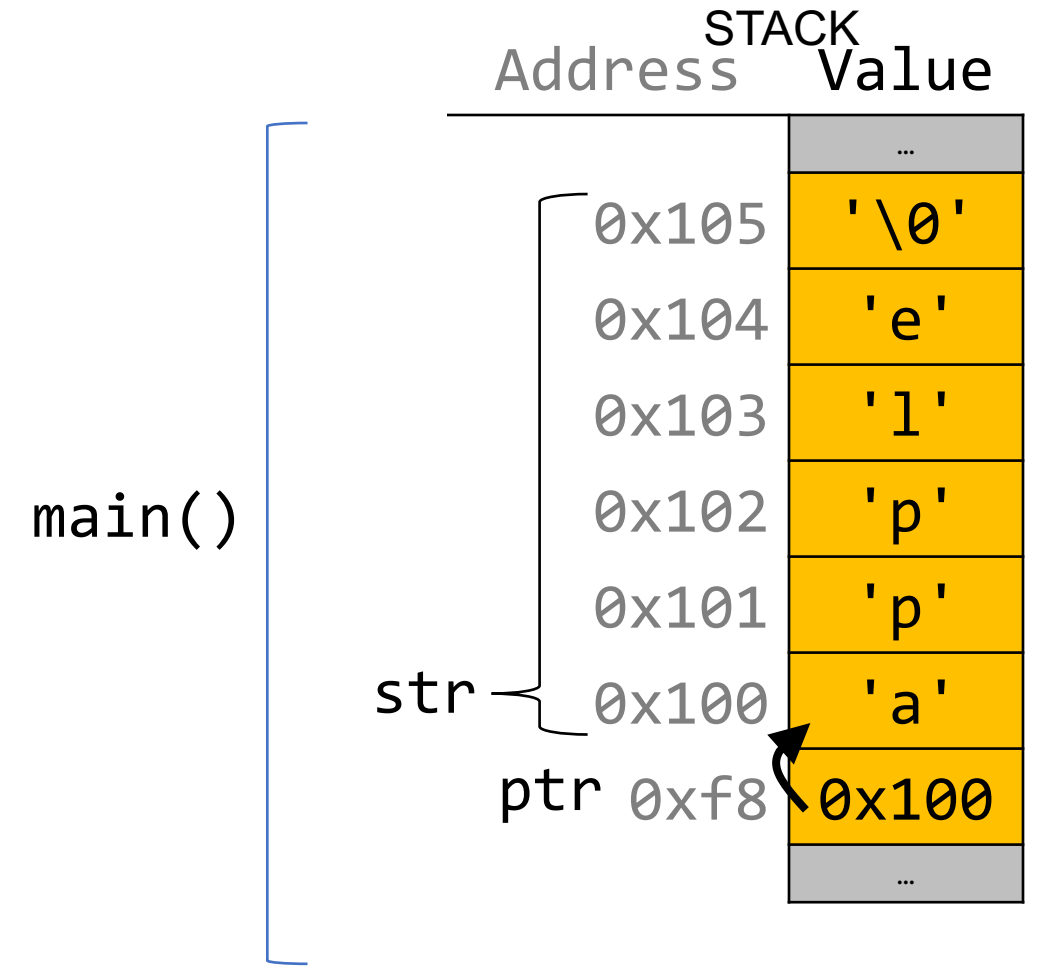
```
int main(int argc, char *argv[]) {
      char str[6];
      strcpy(str, "apple");
      char *ptr = str;
      ...
}
```



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.

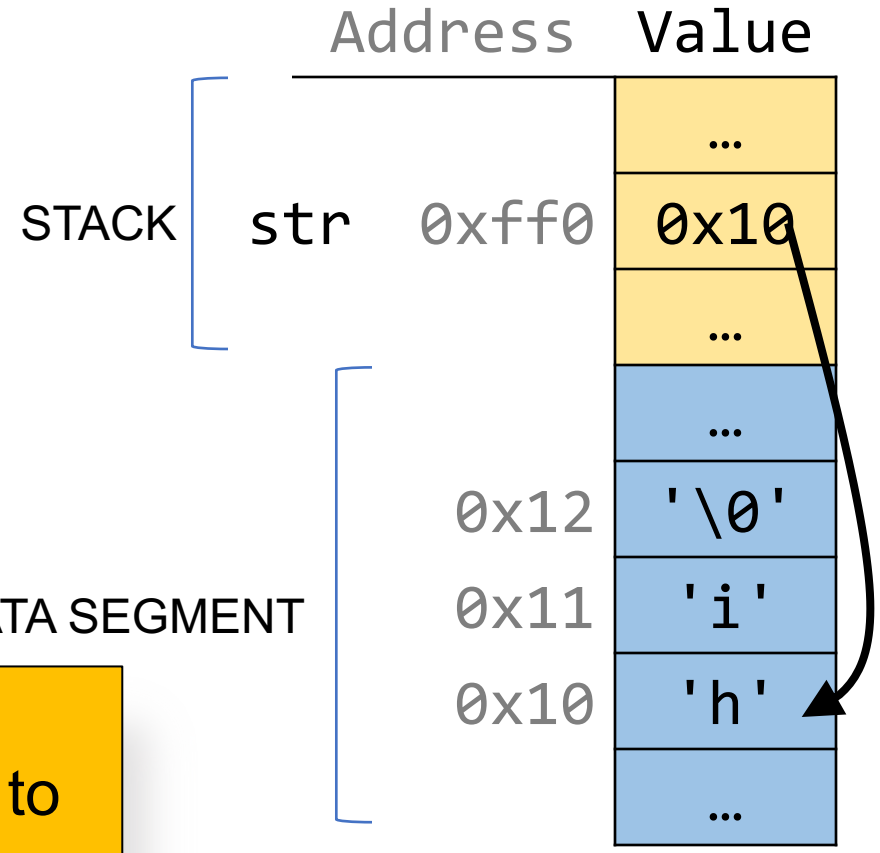
```
char *myString = "Hello, world!";
...
printf("%s", myString);                    // Hello, world!
```

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 **dst** 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);
}

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?

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

```
void skipSpaces(__1__) {
    ...
}

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

What should go in each of the blanks so that this code correctly modifies str to skip leading spaces?

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

Exercise 3

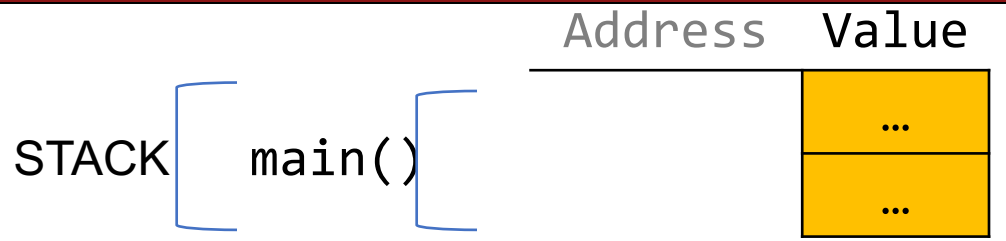
Sometimes, we would like to modify a string's pointer itself, rather than just the characters it points to. E.g. we want to write a function **skipSpaces** that modifies a string pointer to skip past any initial spaces. What should go in each of the blanks?

```
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.

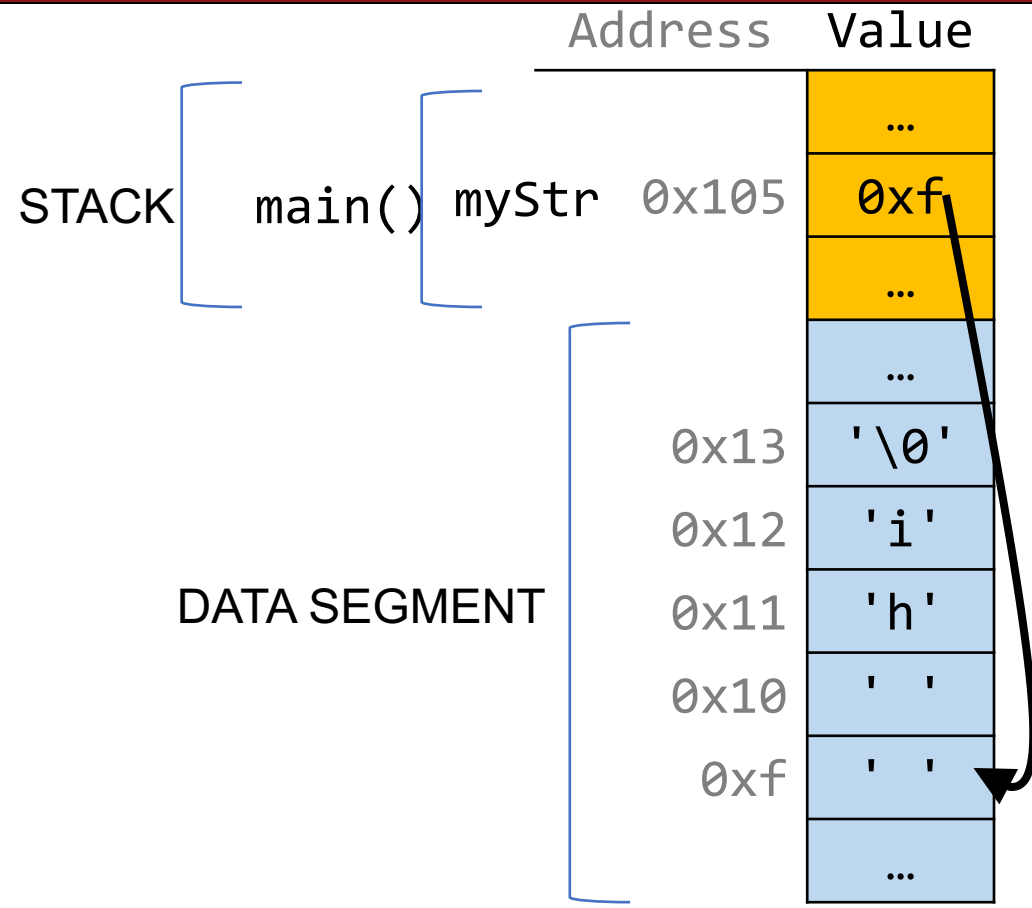
Pointers to Strings

```
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;
}
```



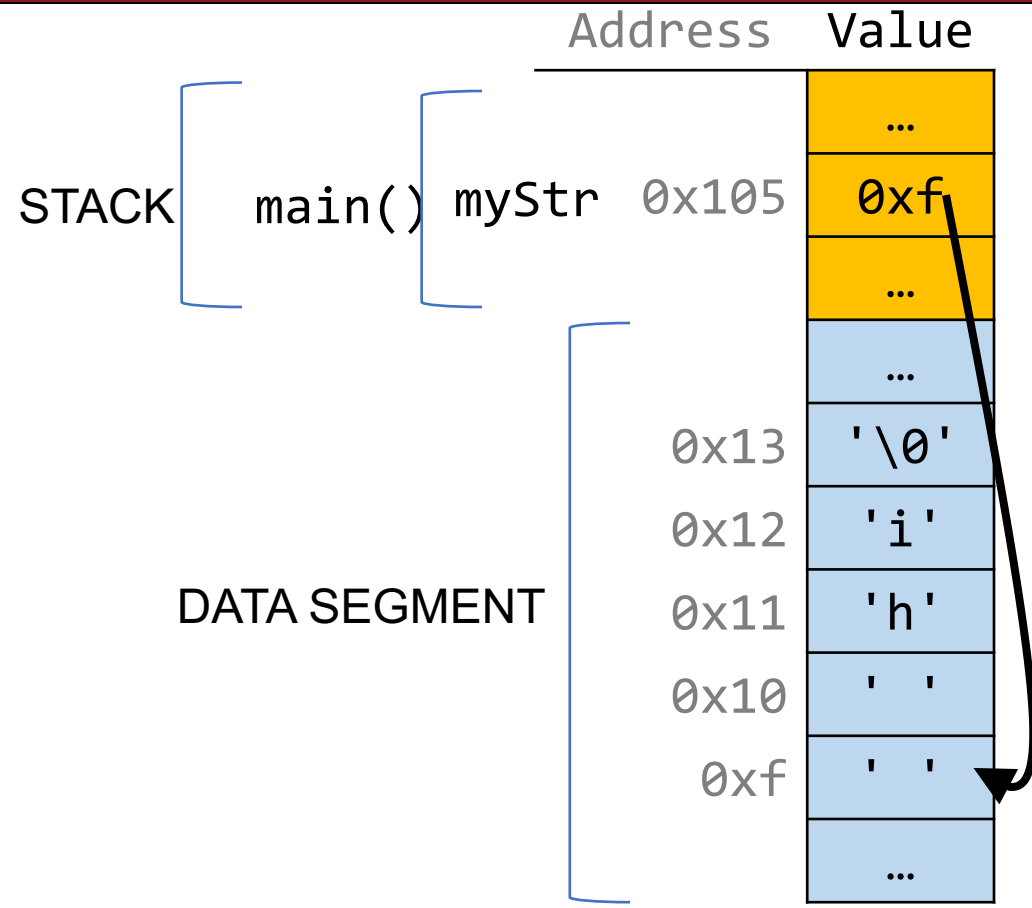
Pointers to Strings

```
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;
}
```



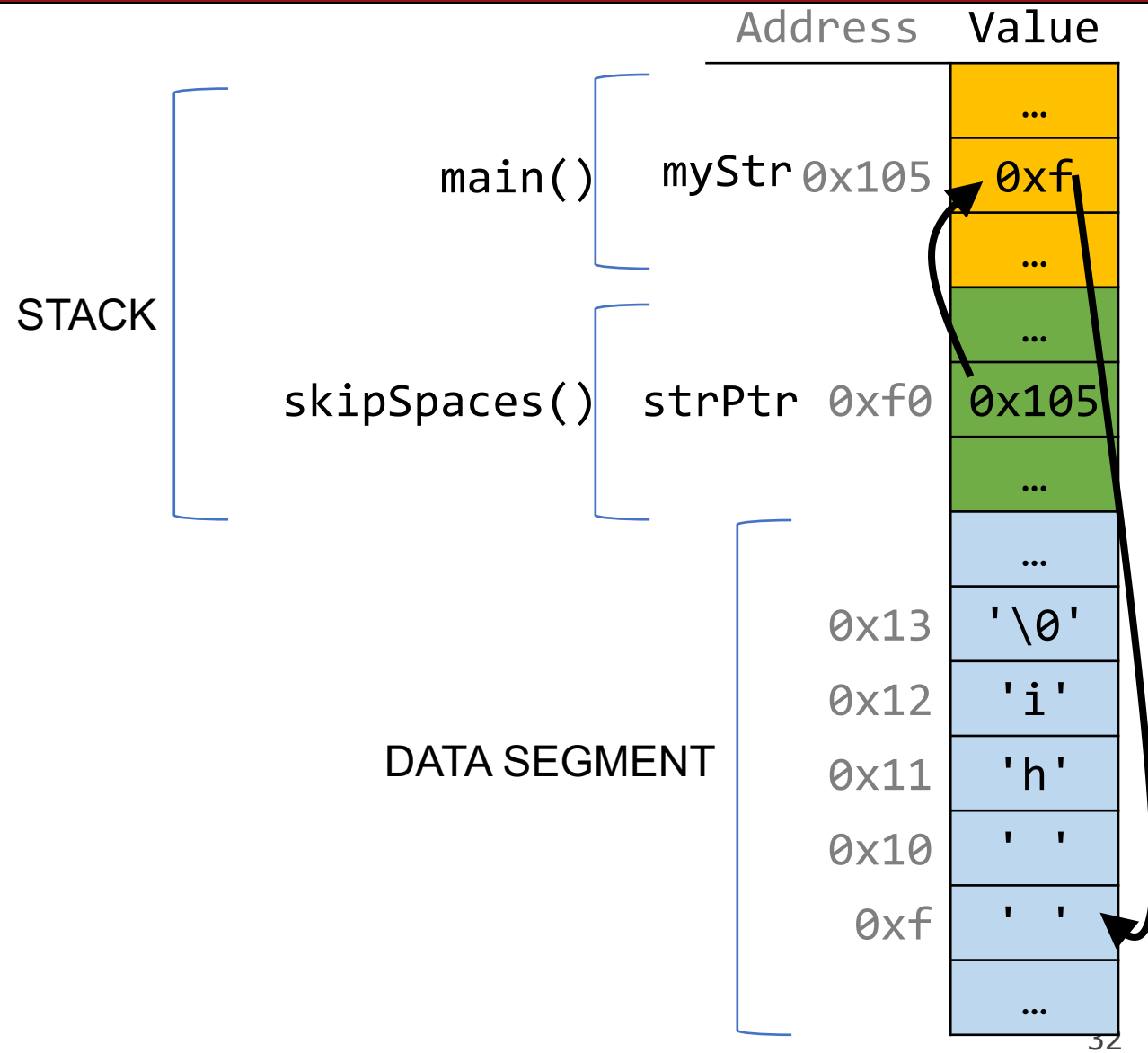
Pointers to Strings

```
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;
}
```



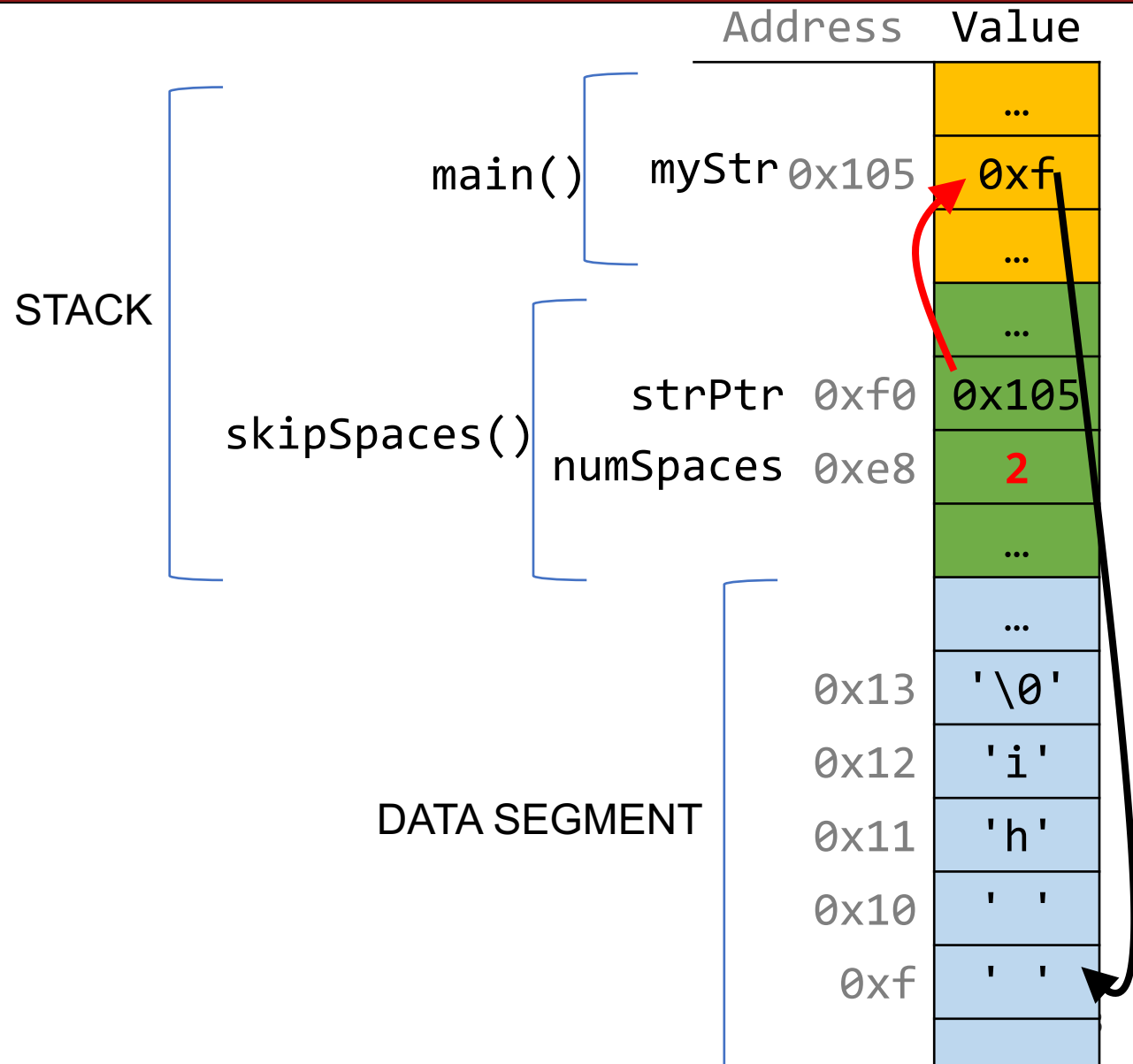
Pointers to Strings

```
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;
}
```



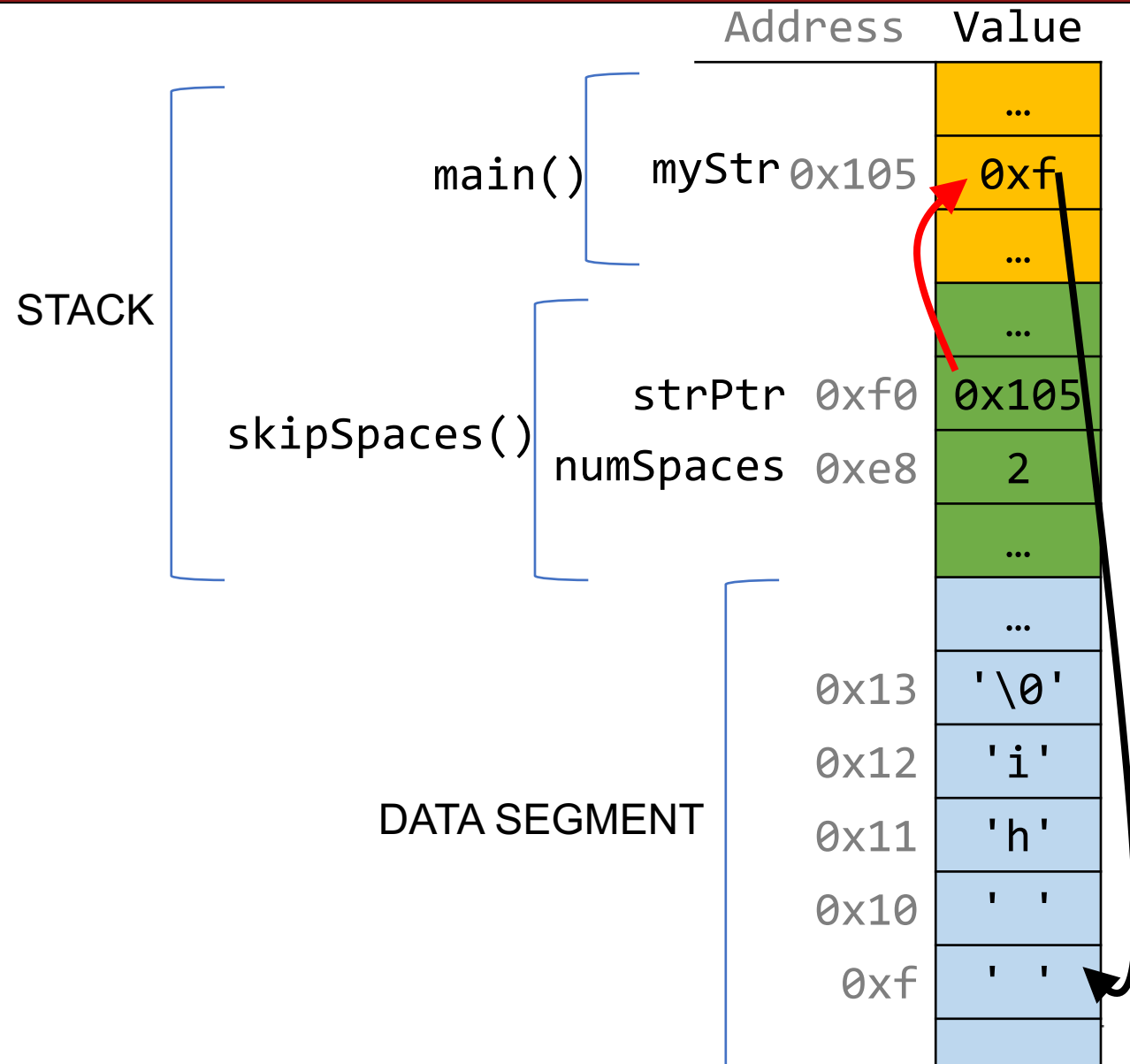
Pointers to Strings

```
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;
}
```



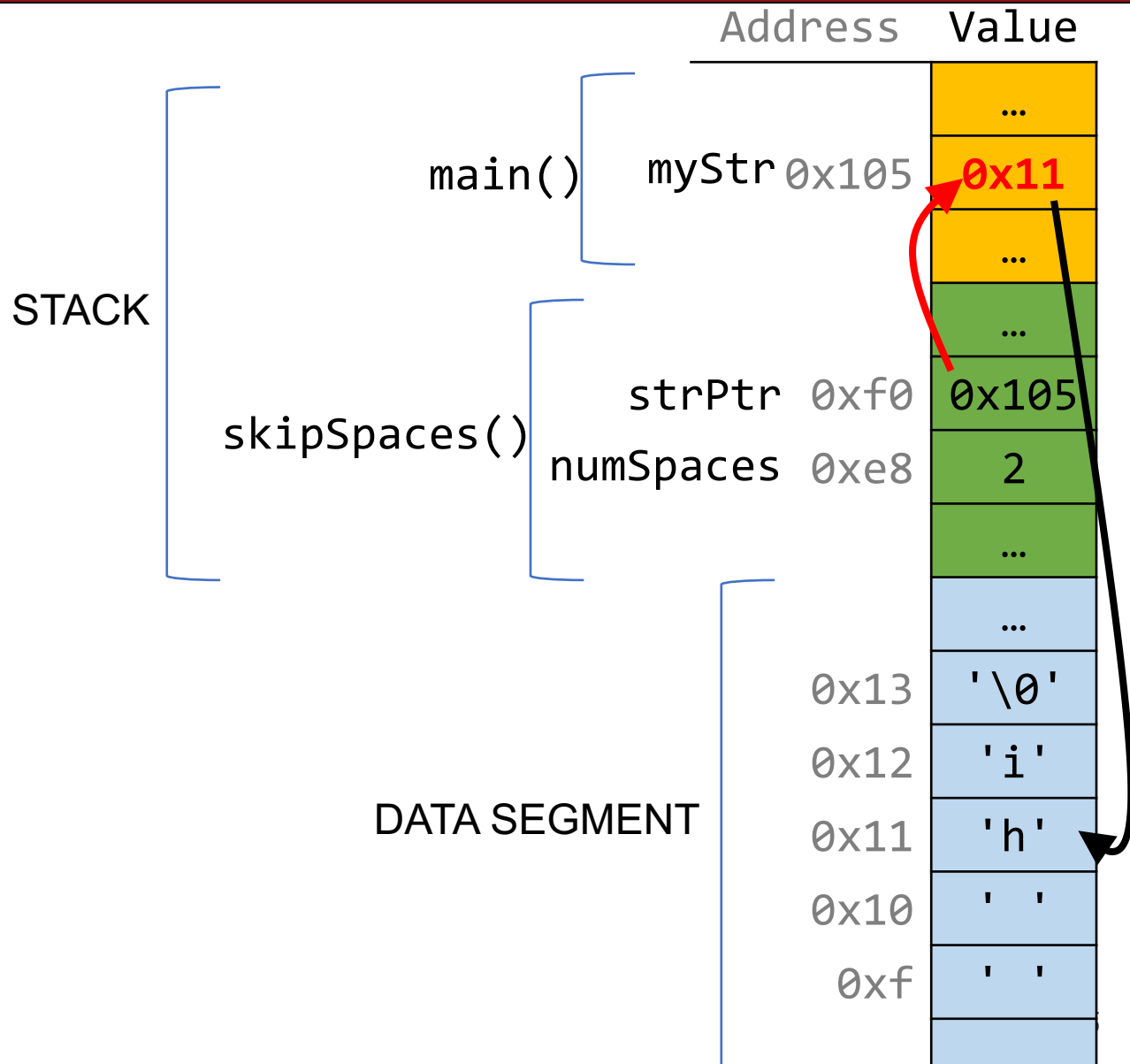
Pointers to Strings

```
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;
}
```



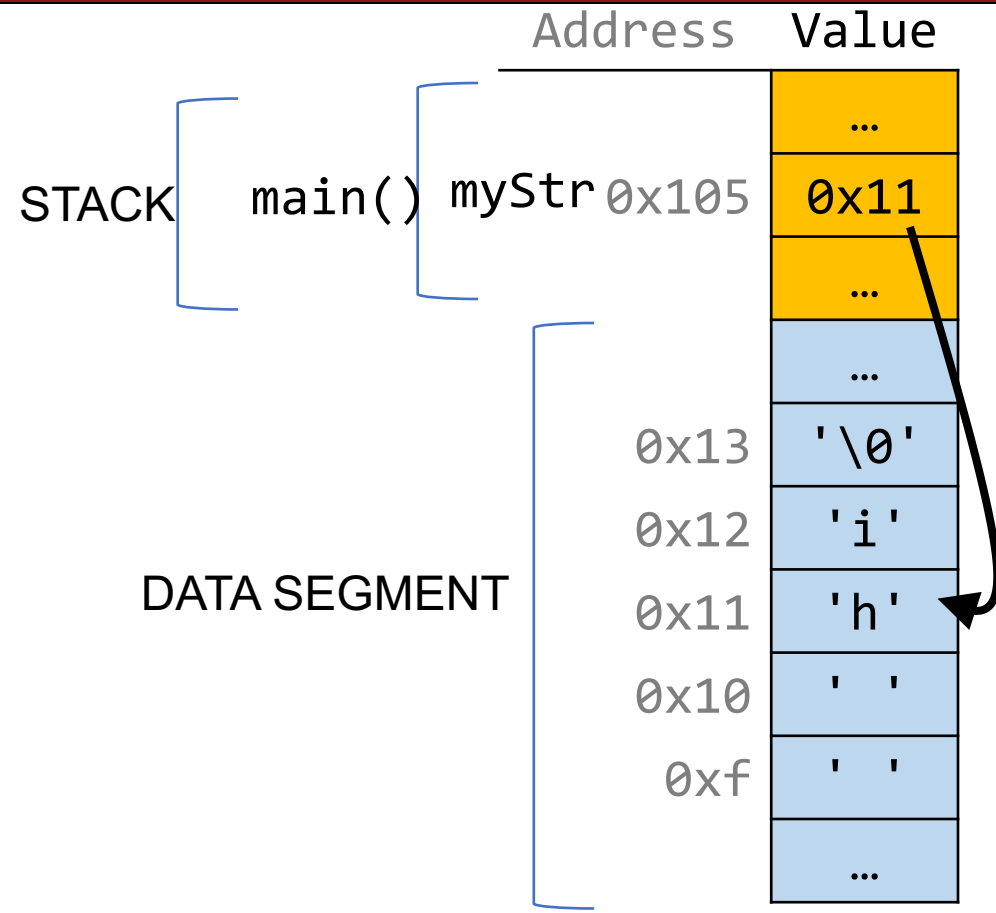
Pointers to Strings

```
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;
}
```



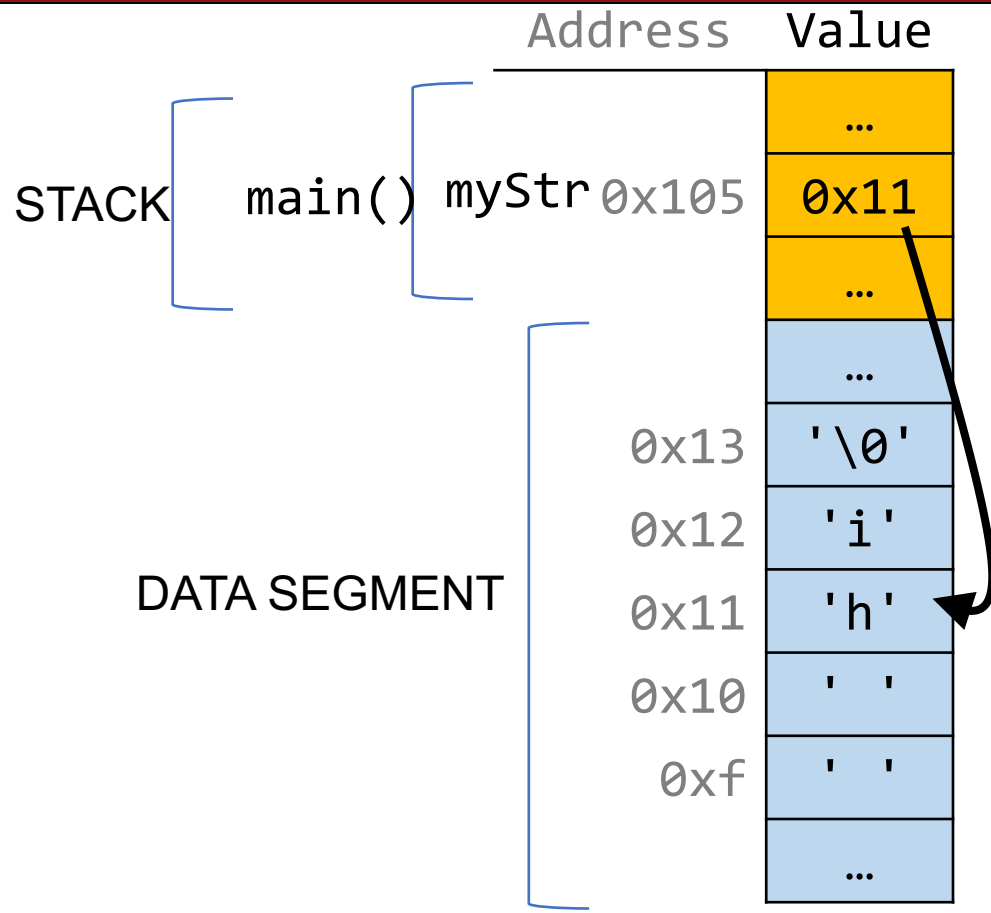
Pointers to Strings

```
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

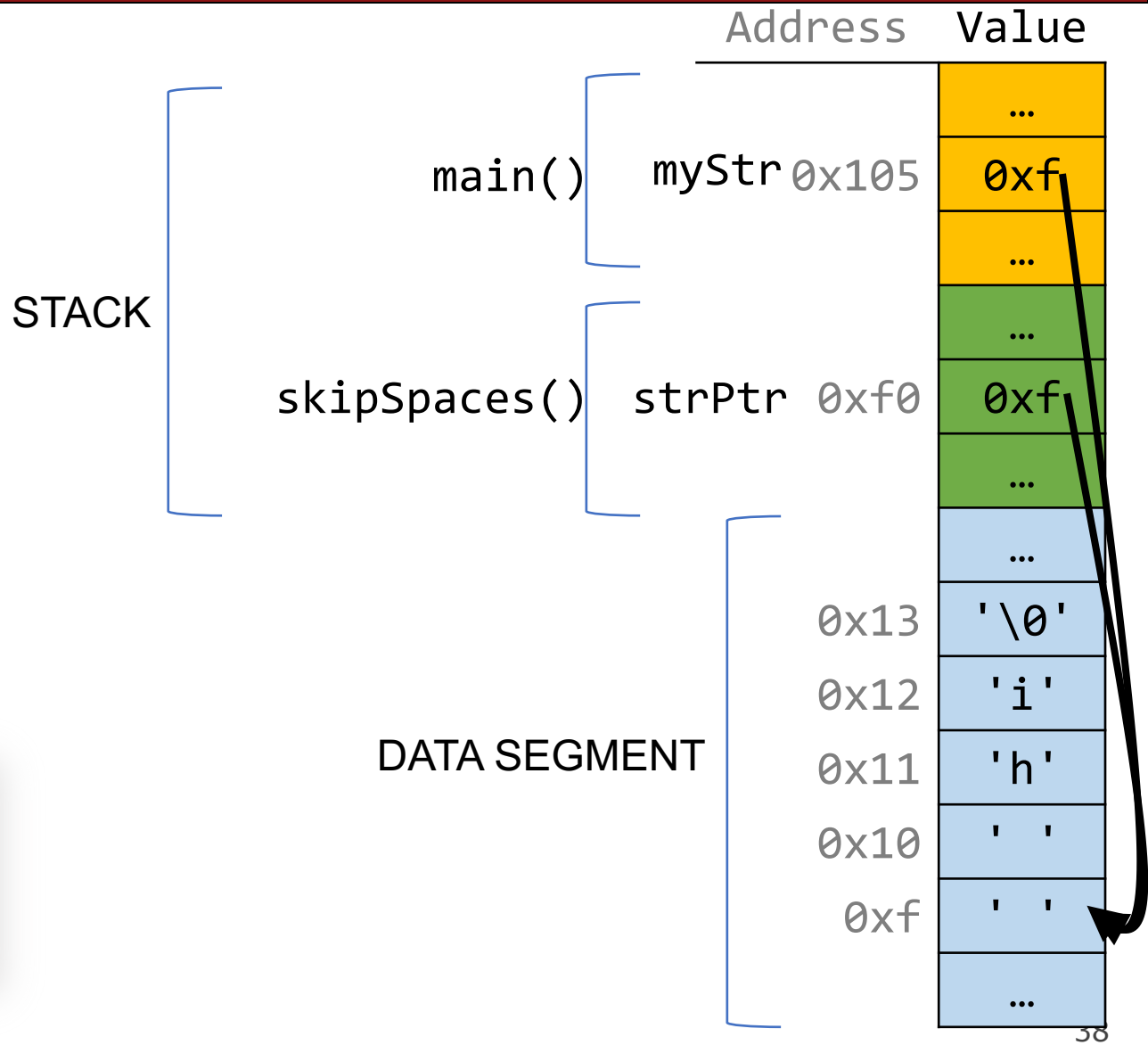
```
void skipSpaces(char **strPtr) {
    int numSpaces = strspn(*strPtr, " ");
    *strPtr += numSpaces;
}

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 eulo3

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

Line B: Segmentation fault (string literal)

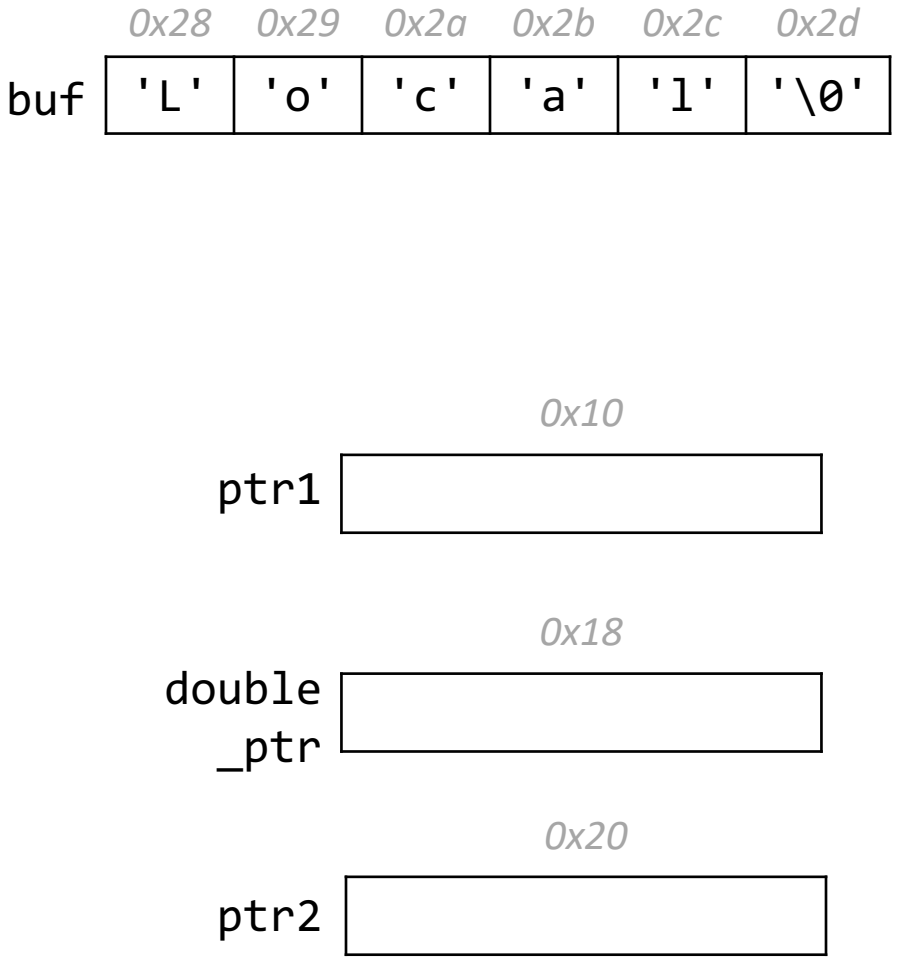
3. Bonus: Tricky addresses

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

What is stored in each variable?

3. Bonus: Tricky addresses

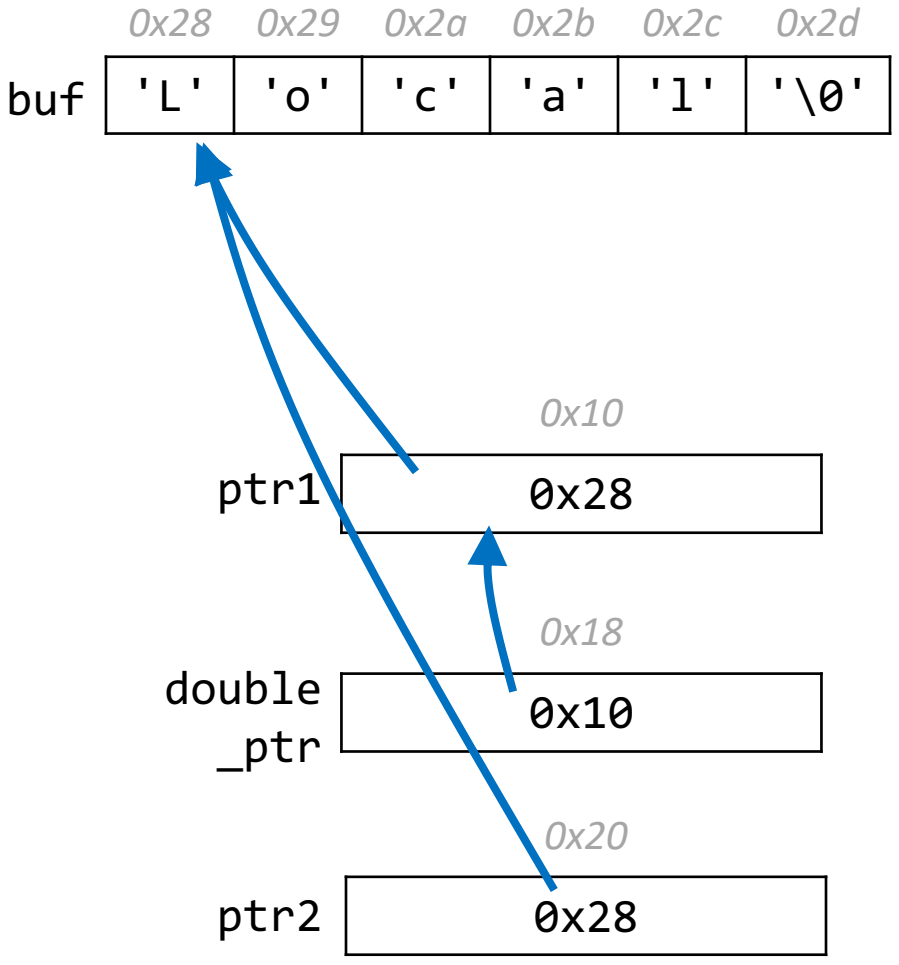
```
1  void tricky_addresses() {
2    char buf[] = "Local";
3    char *ptr1 = buf;
4    char **double_ptr = &ptr1;
5    printf("ptr1's value:     %p\n", ptr1);
6    printf("ptr1’s deref    : %c\n", *ptr1);
7    printf("       address:   %p\n", &ptr1);
8    printf("double_ptr value: %p\n", double_ptr);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

10   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**.

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

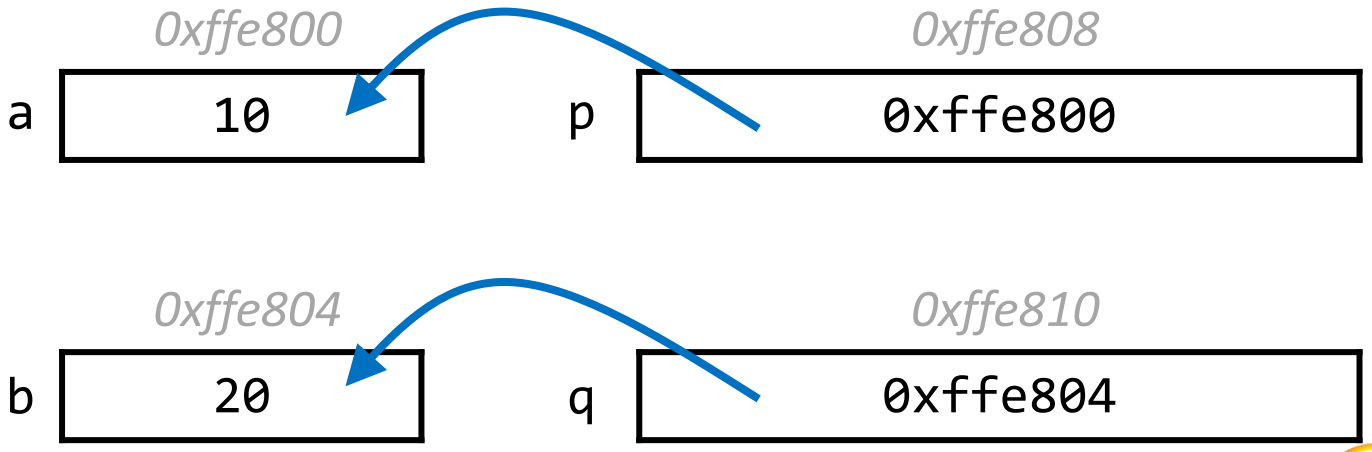


While Line 10 raises a compiler warning, functionally it will still work—because pointers are **addresses**.

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 }
```

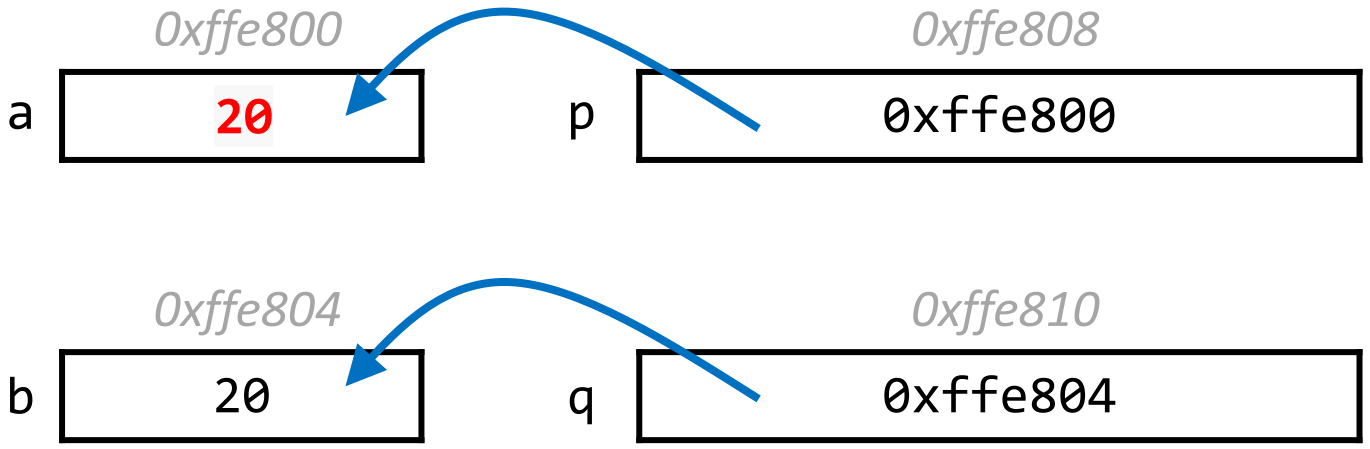
- Lines 2-5: Draw a diagram.
- Line 7: Update your diagram.
- Line 8: Update your diagram.



Pen and paper: A * Wars Story

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

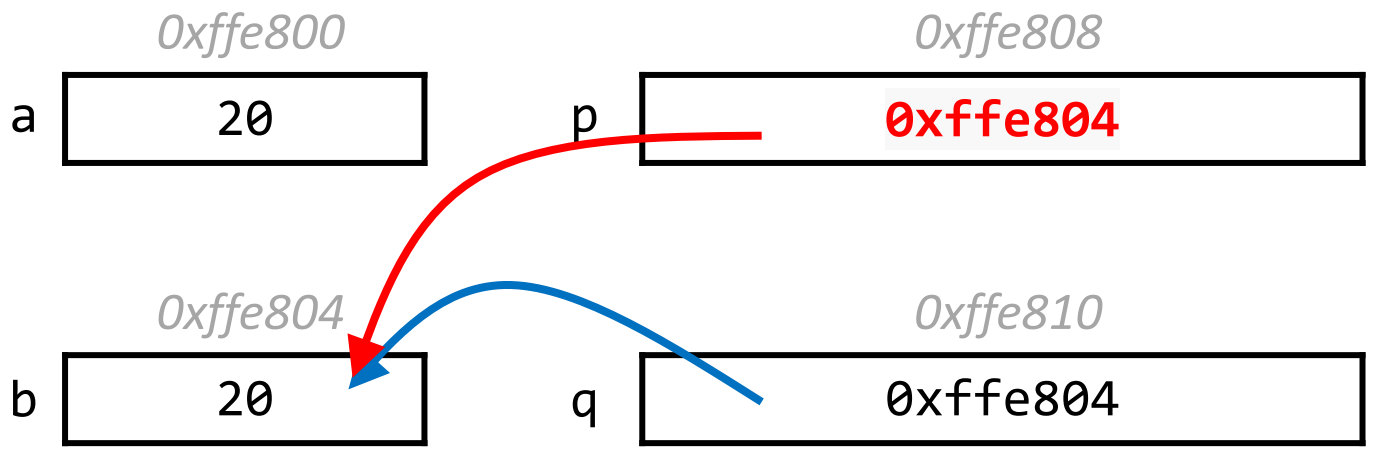
- Lines 2-5: Draw a diagram.
- Line 7: Update your diagram.
- Line 8: Update your diagram.



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 }
```

- 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';
```

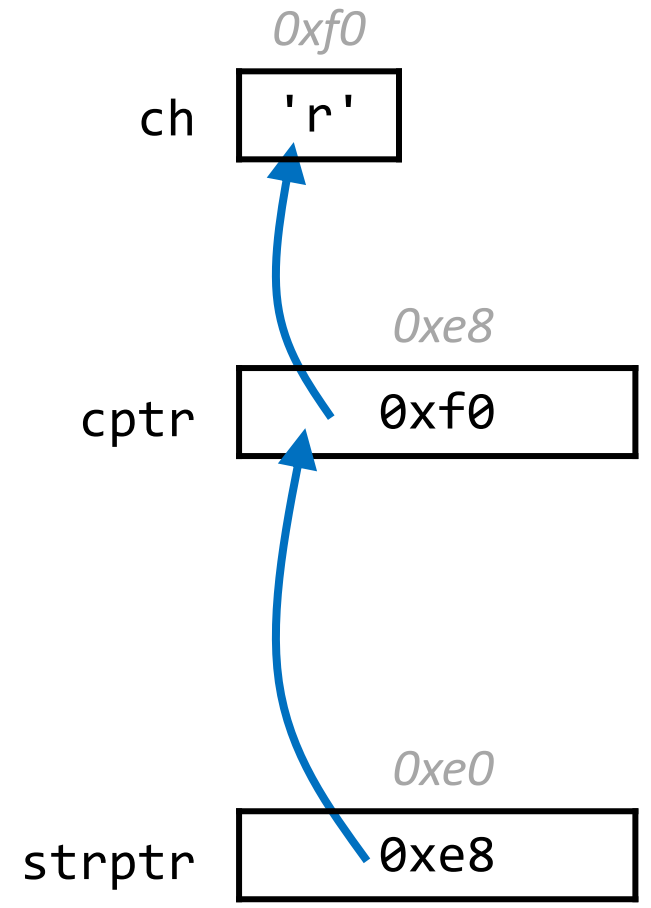
ch stores a char

```
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 *)

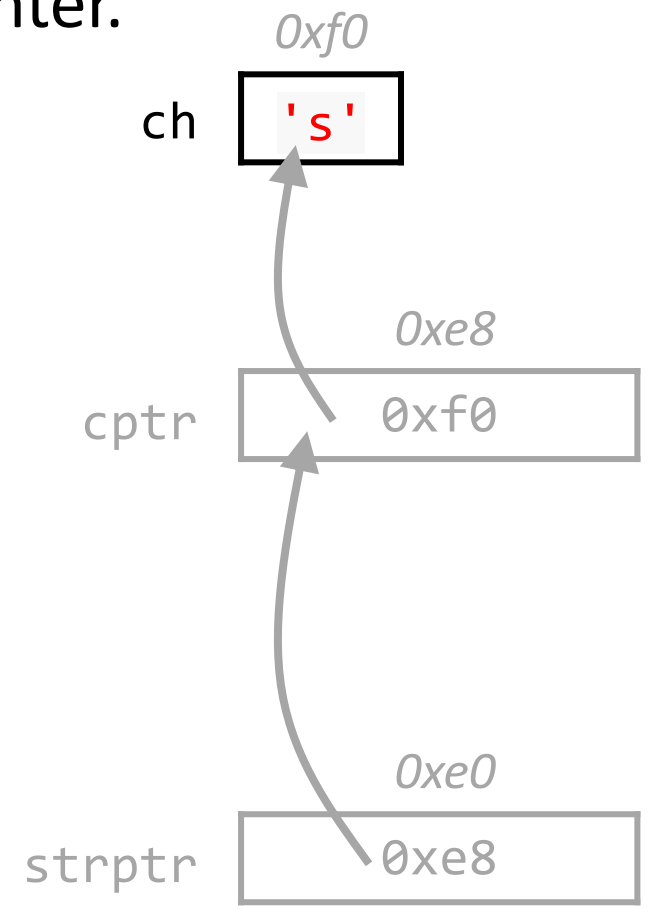


* Wars: Episode II (of 2)

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.

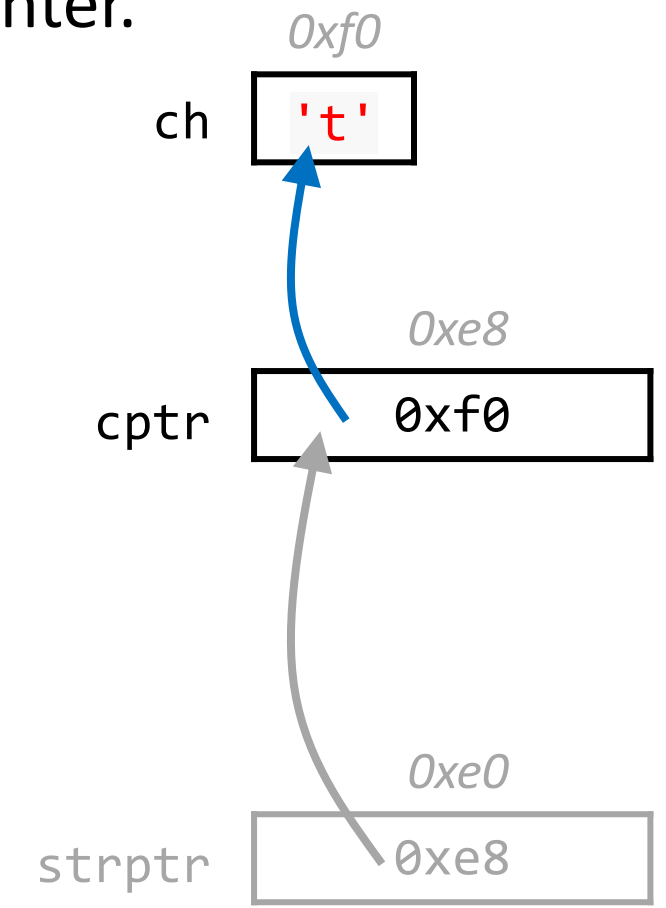
```
char ch = 'r';
ch = ch + 1;
```

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;
```

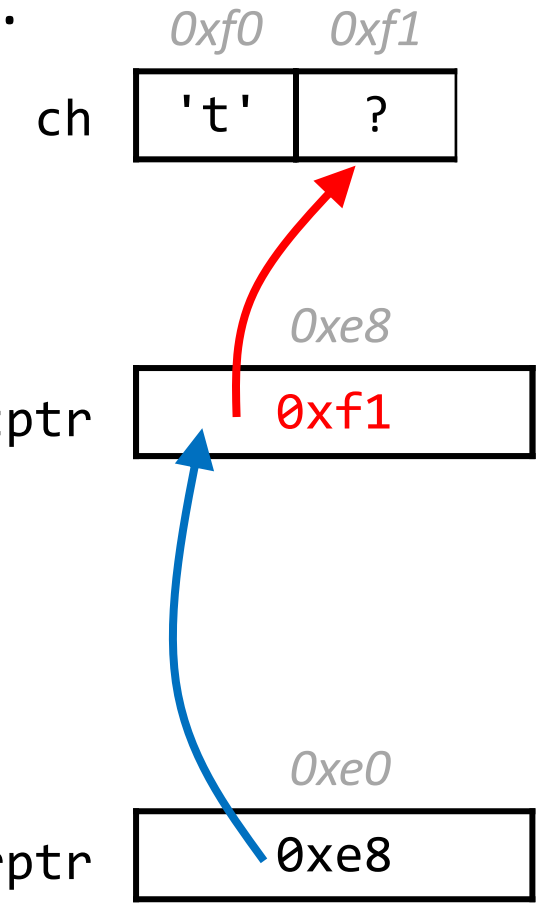
Increment value stored in ch

```
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**)

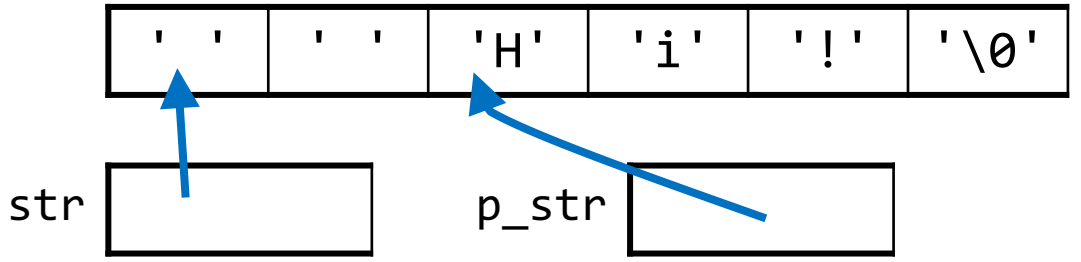


Skip spaces

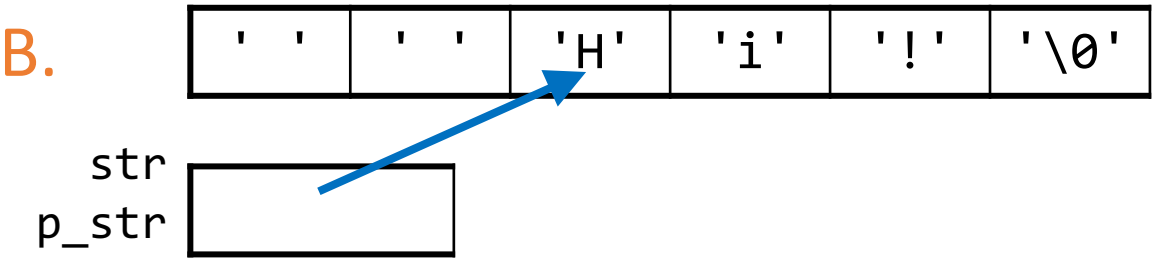
```
1  void skip_spaces(char **p_str) {
2    int num = strspn(*p_str, " ");
3    *p_str = *p_str + num;
4  }
5  int main(int argc, char *argv[]){
6    char *str = "  Hi!";
7    skip_spaces(&str);
8    printf("%s", str); // "Hi!"
9    return 0;
10 }
```

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

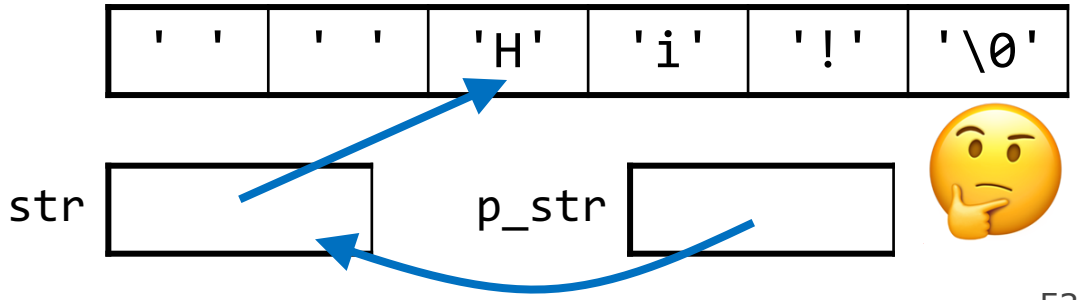
A.



B.



C.

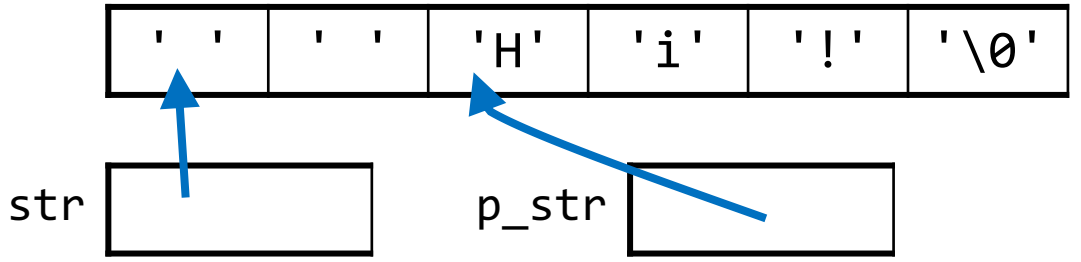


Skip spaces

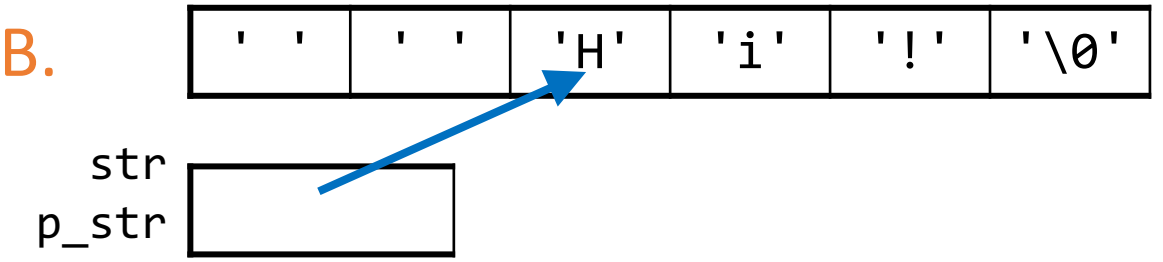
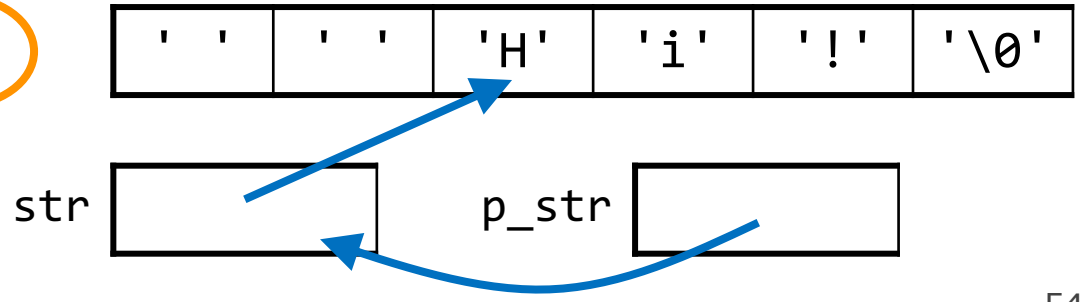
```
1  void skip_spaces(char **p_str) {
2    int num = strspn(*p_str, " ");
3    *p_str = *p_str + num;
4  }
5  int main(int argc, char *argv[]){
6    char *str = "  Hi!";
7    skip_spaces(&str);
8    printf("%s", str); // "Hi!"
9    return 0;
10 }
```

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

A.



B.



C.