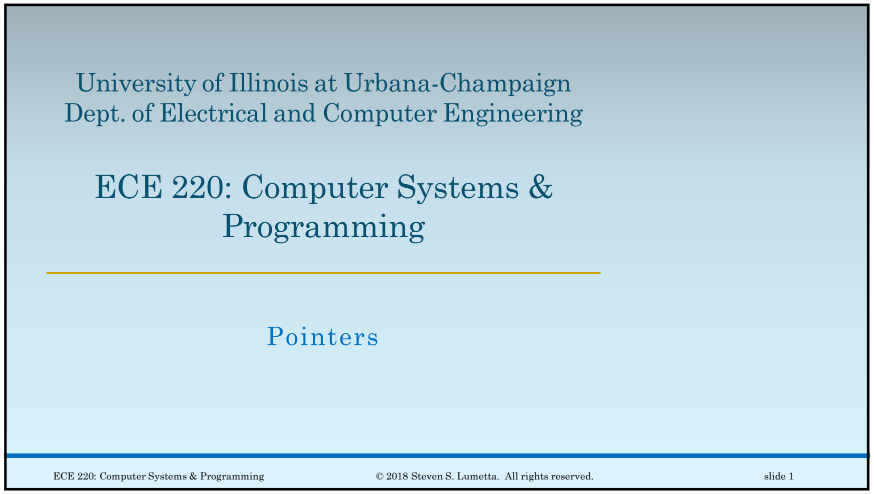
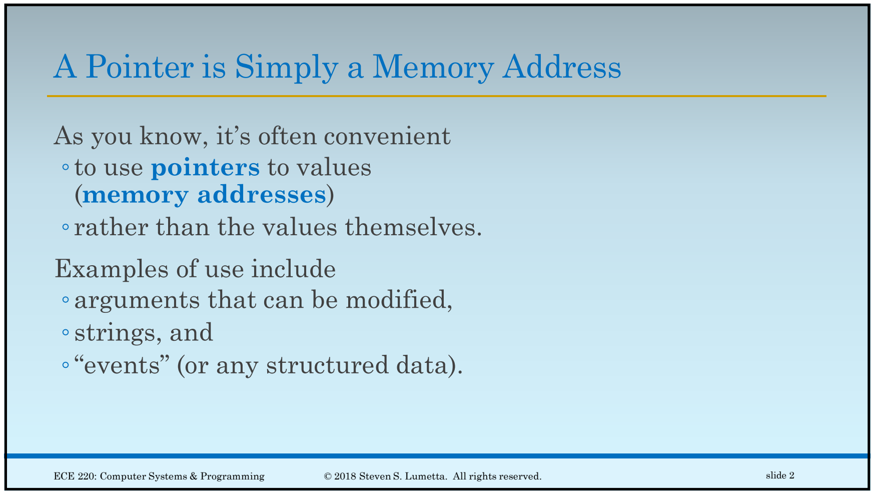


University of Illinois at Urbana-Champaign
Dept. of Electrical and Computer Engineering

ECE 220: Computer Systems & Programming

Pointers

ECE 220: Computer Systems & Programming slide 1



A Pointer is Simply a Memory Address

As you know, it's often convenient
- to use **pointers** to values (**memory addresses**)
- rather than the values themselves.

Examples of use include
- arguments that can be modified,
- strings, and
- "events" (or any structured data).

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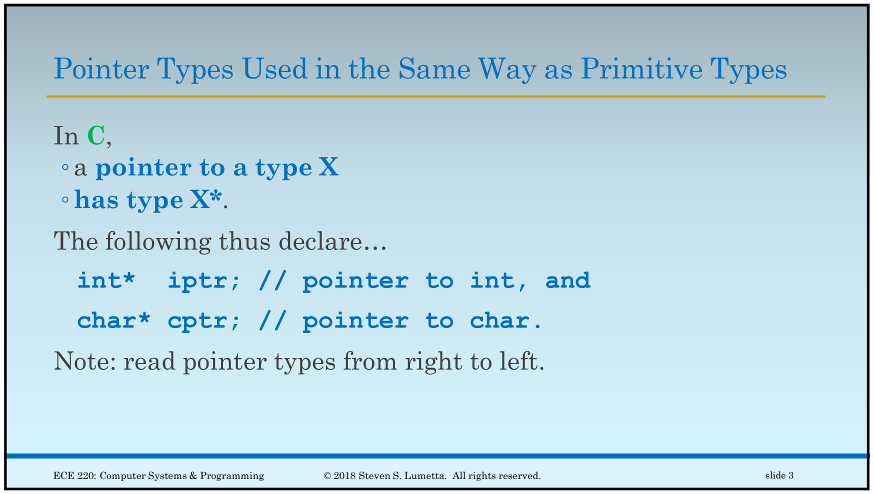

Pointer Types Used in the Same Way as Primitive Types

In **C**,
- a **pointer to a type X**
- **has type X***.

The following thus declare…

```
int*  iptr; // pointer to int, and
char* cptr; // pointer to char.
```

Note: read pointer types from right to left.

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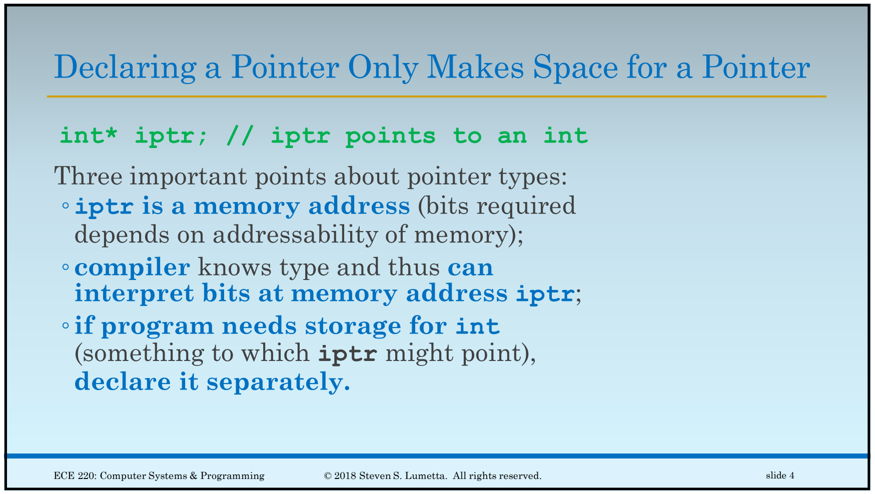

Declaring a Pointer Only Makes Space for a Pointer

```
int* iptr; // iptr points to an int
```

Three important points about pointer types:
- **iptr is a memory address** (bits required depends on addressability of memory);
- **compiler** knows type and thus **can interpret bits at memory address iptr**;
- **if program needs storage for int** (something to which **iptr** might point), **declare it separately.**

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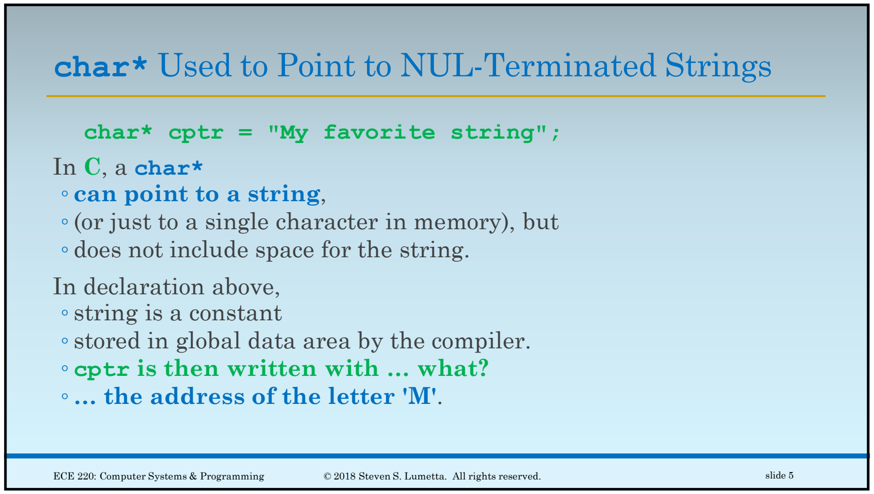


char* Used to Point to NUL-Terminated Strings

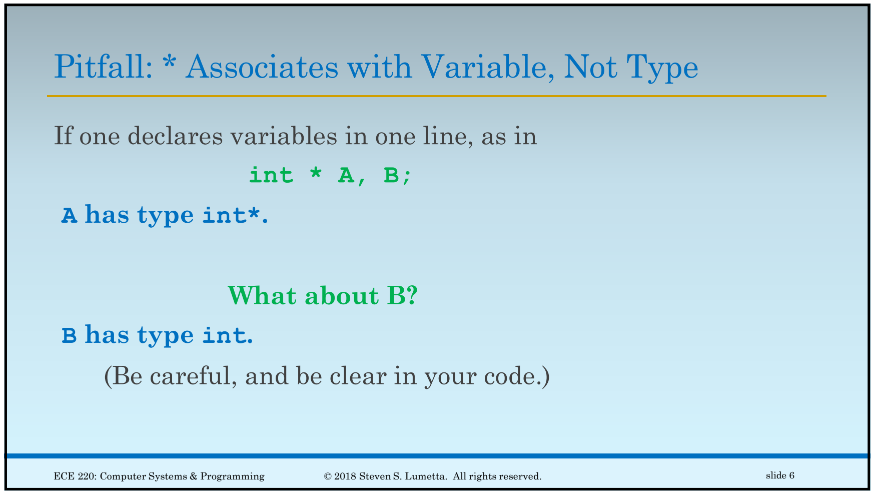
```
char* cptr = "My favorite string";
```

In **C**, a **char***

- **can point to a string**,
- (or just to a single character in memory), but
- does not include space for the string.

In declaration above,

- string is a constant
- stored in global data area by the compiler.
- **cptr is then written with … what?**
- **… the address of the letter 'M'**.



Pitfall: * Associates with Variable, Not Type

If one declares variables in one line, as in

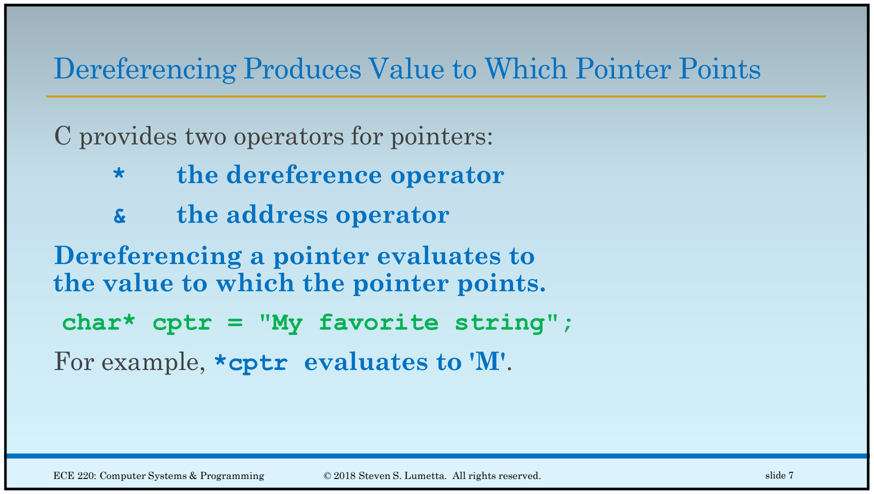
```
int * A, B;
```

A has type int*.

What about B?

B has type int.

(Be careful, and be clear in your code.)



Dereferencing Produces Value to Which Pointer Points

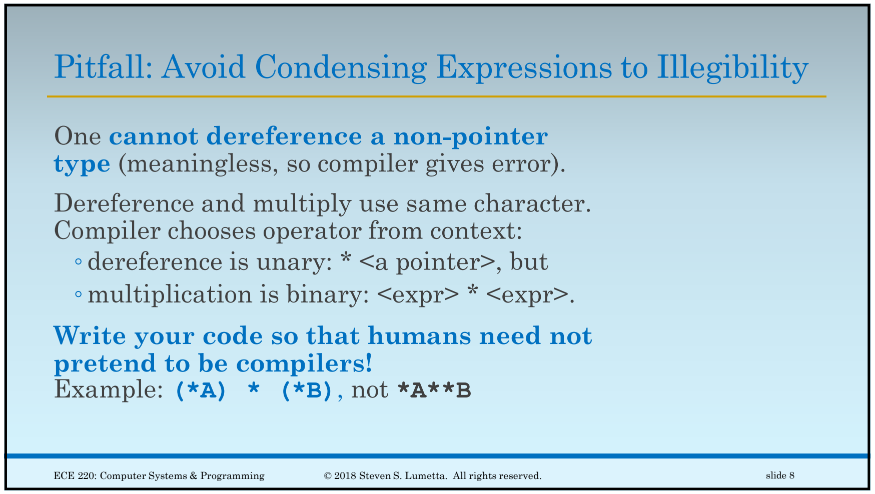
C provides two operators for pointers:

*****	**the dereference operator**
&	**the address operator**

Dereferencing a pointer evaluates to the value to which the pointer points.

```
char* cptr = "My favorite string";
```

For example, ***cptr evaluates to 'M'**.



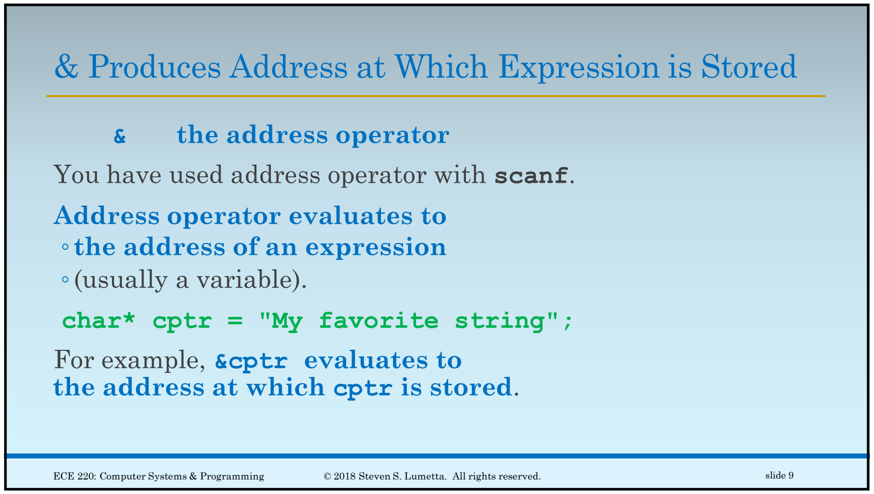
Pitfall: Avoid Condensing Expressions to Illegibility

One **cannot dereference a non-pointer type** (meaningless, so compiler gives error).

Dereference and multiply use same character. Compiler chooses operator from context:

- dereference is unary: * <a pointer>, but
- multiplication is binary: <expr> * <expr>.

Write your code so that humans need not pretend to be compilers!
Example: **(*A) * (*B)**, not ***A**B**



& Produces Address at Which Expression is Stored

`&`   the address operator

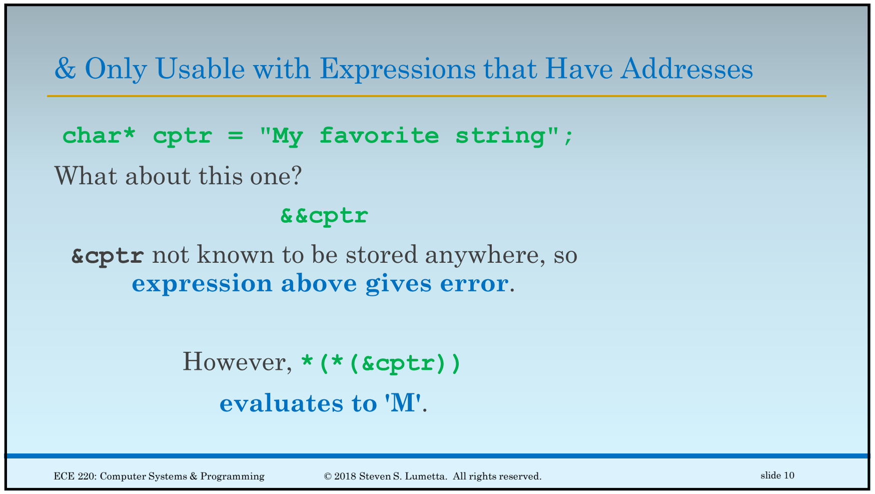
You have used address operator with **`scanf`**.

Address operator evaluates to

- **the address of an expression**
- (usually a variable).

```
char* cptr = "My favorite string";
```

For example, **`&cptr` evaluates to the address at which `cptr` is stored**.



& Only Usable with Expressions that Have Addresses

```
char* cptr = "My favorite string";
```

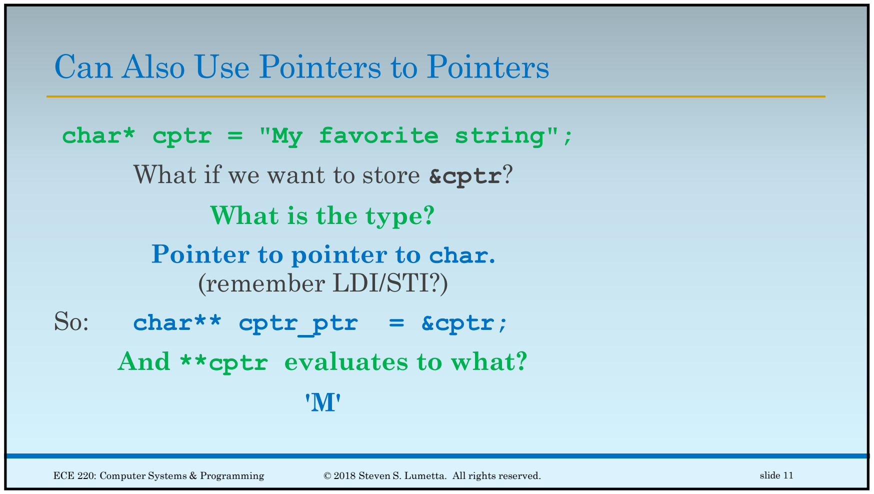
What about this one?

`&&cptr`

`&cptr` not known to be stored anywhere, so **expression above gives error**.

However, **`*(*(&cptr))`**

evaluates to 'M'.



Can Also Use Pointers to Pointers

```
char* cptr = "My favorite string";
```

What if we want to store **`&cptr`**?

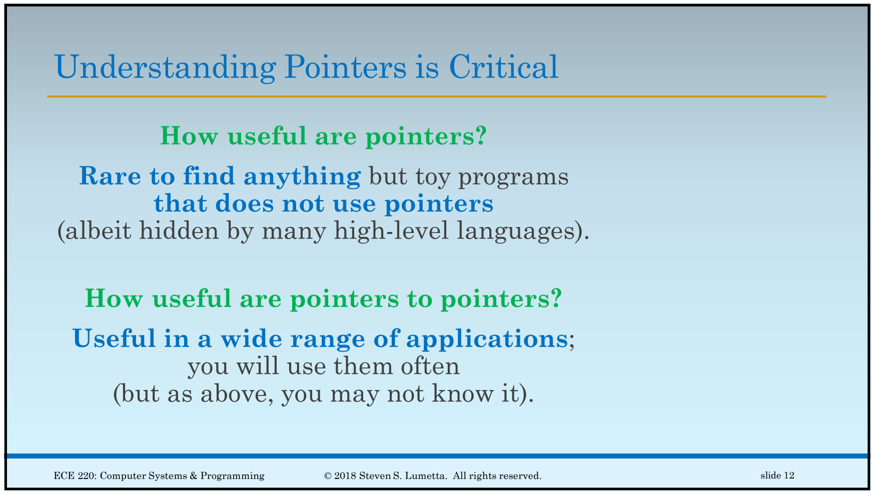
What is the type?

Pointer to pointer to char.
(remember LDI/STI?)

So: **`char** cptr_ptr = &cptr;`**

And `**cptr` evaluates to what?

'M'



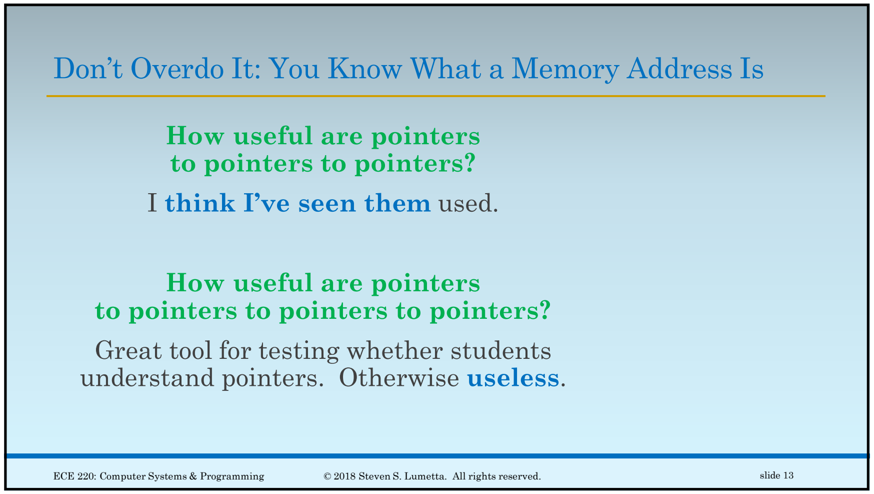
Understanding Pointers is Critical

How useful are pointers?

Rare to find anything but toy programs **that does not use pointers** (albeit hidden by many high-level languages).

How useful are pointers to pointers?

Useful in a wide range of applications; you will use them often (but as above, you may not know it).



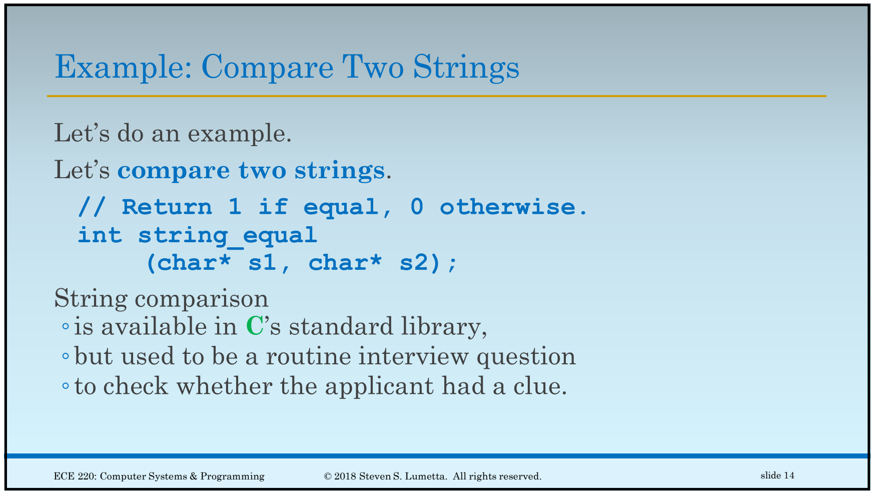
Don't Overdo It: You Know What a Memory Address Is

How useful are pointers to pointers to pointers?

I **think I've seen them** used.

How useful are pointers to pointers to pointers to pointers?

Great tool for testing whether students understand pointers. Otherwise **useless**.



Example: Compare Two Strings

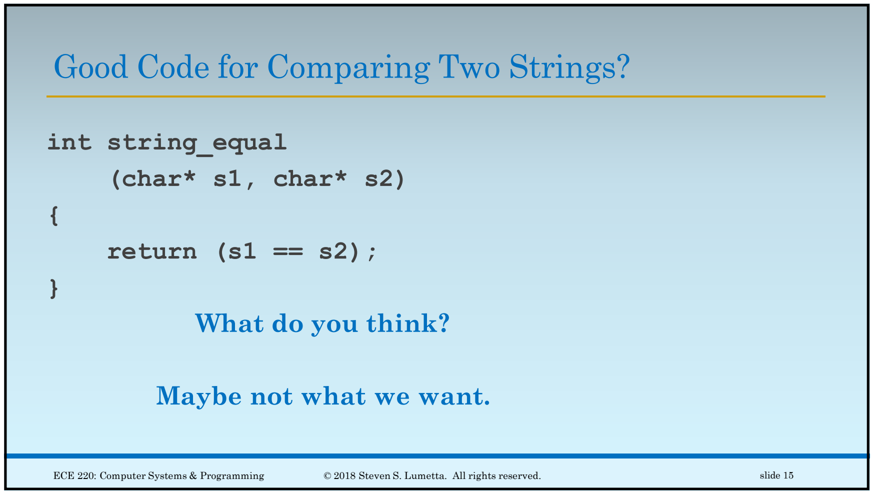
Let's do an example.

Let's **compare two strings**.

```
// Return 1 if equal, 0 otherwise.
int string_equal
     (char* s1, char* s2);
```

String comparison

- is available in **C**'s standard library,
- but used to be a routine interview question
- to check whether the applicant had a clue.

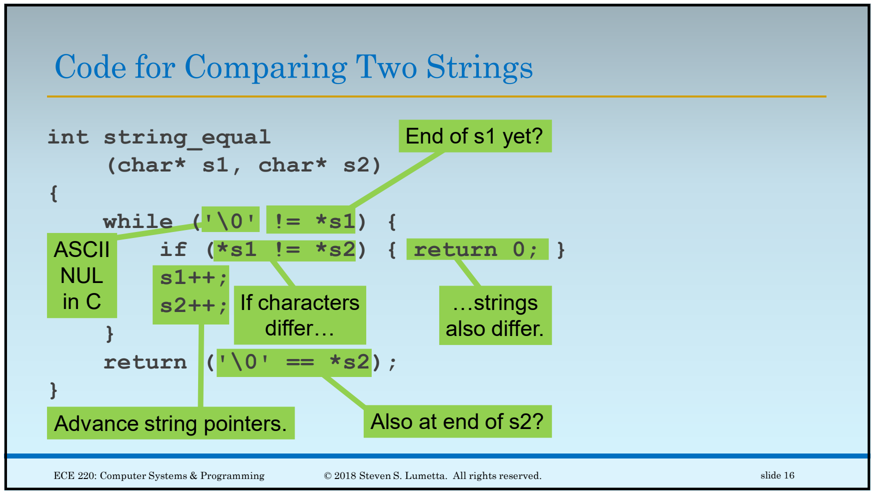


Good Code for Comparing Two Strings?

```
int string_equal
    (char* s1, char* s2)
{
    return (s1 == s2);
}
```

What do you think?

Maybe not what we want.



Code for Comparing Two Strings

```
int string_equal
    (char* s1, char* s2)
{
    while ('\0' != *s1) {
        if (*s1 != *s2) { return 0; }
        s1++;
        s2++;
    }
    return ('\0' == *s2);
}
```

End of s1 yet?

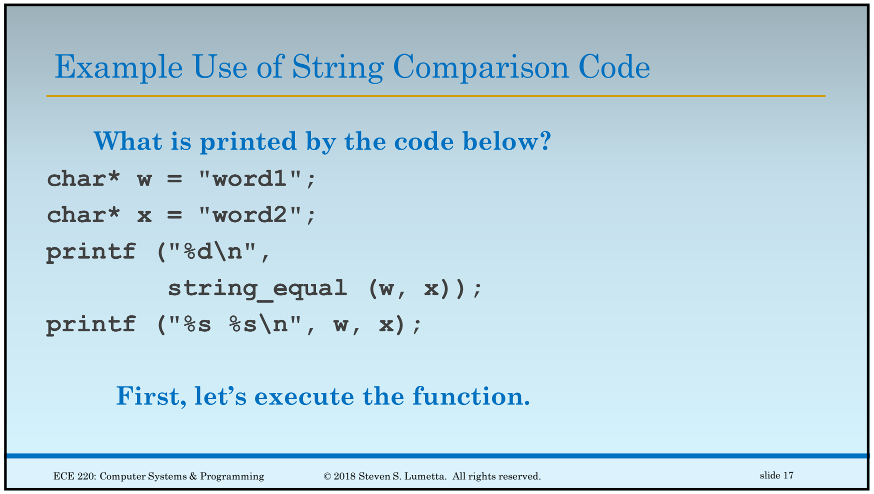
ASCII NUL in C

If characters differ…

…strings also differ.

Advance string pointers.

Also at end of s2?



Example Use of String Comparison Code

What is printed by the code below?

```
char* w = "word1";
char* x = "word2";
printf ("%d\n",
        string_equal (w, x));
printf ("%s %s\n", w, x);
```

First, let's execute the function.

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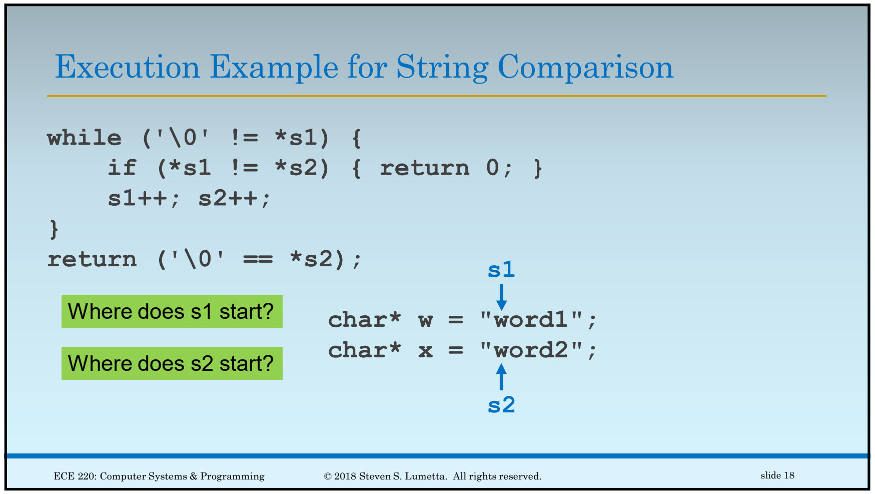

Execution Example for String Comparison

```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

Where does s1 start?

Where does s2 start?

```
char* w = "word1";
char* x = "word2";
```

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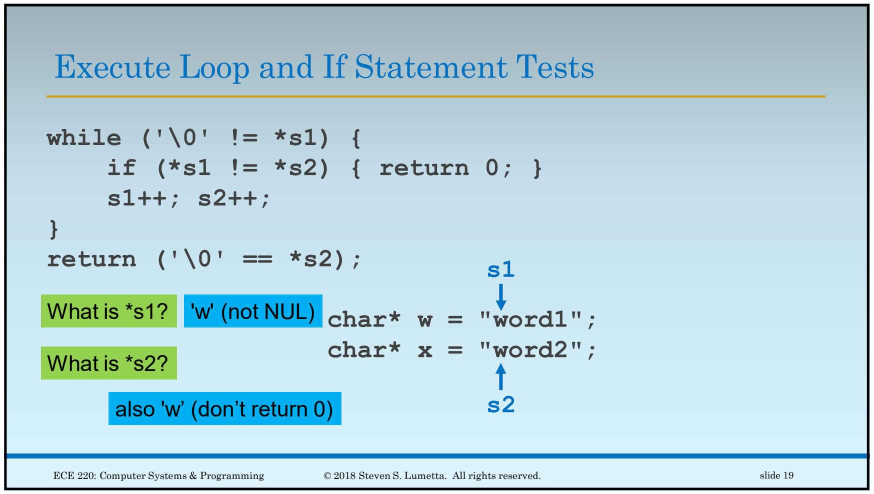

Execute Loop and If Statement Tests

```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

What is *s1? 'w' (not NUL)

What is *s2?

also 'w' (don't return 0)

```
char* w = "word1";
char* x = "word2";
```

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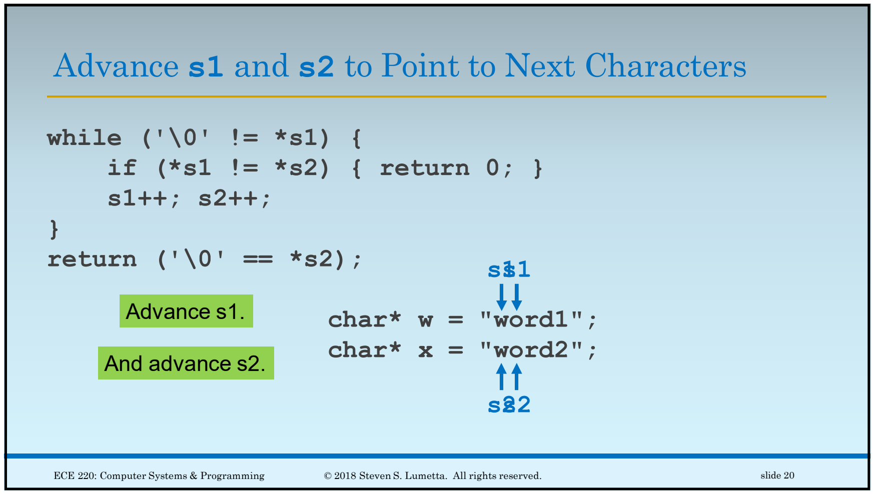

Advance **s1** and **s2** to Point to Next Characters

```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

Advance s1.

And advance s2.

```
char* w = "word1";
char* x = "word2";
```

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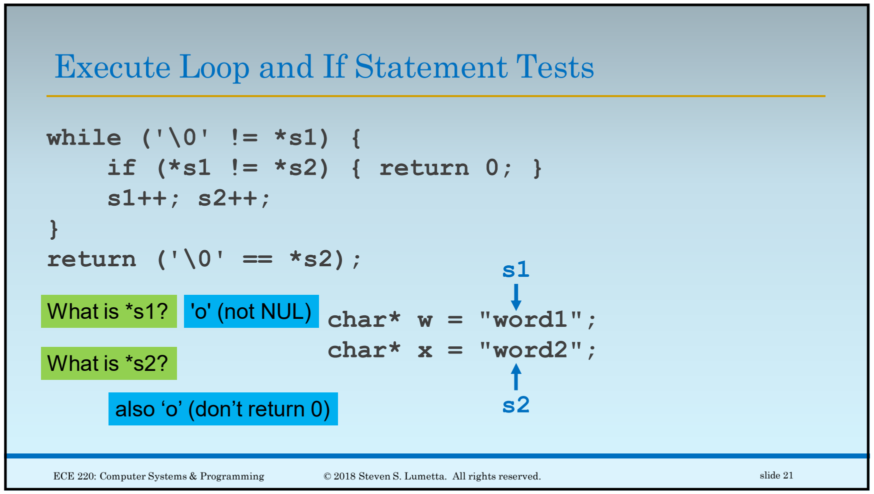


Execute Loop and If Statement Tests

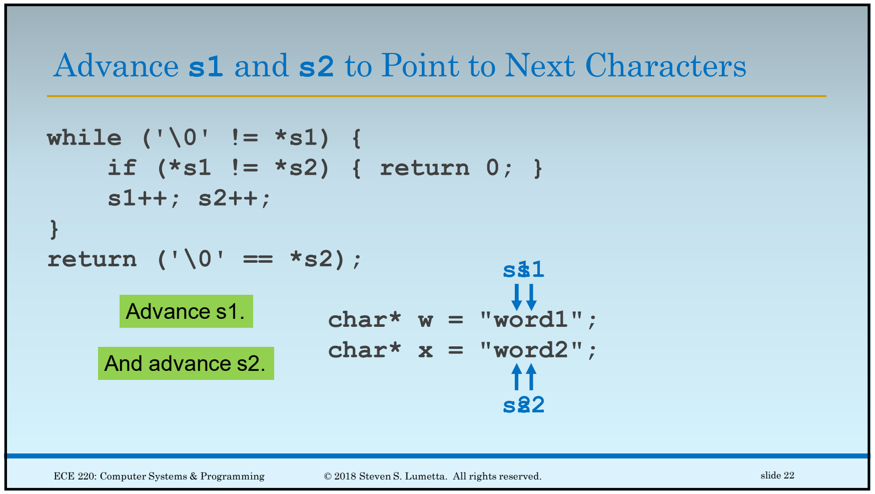
```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

What is *s1? 'o' (not NUL)

What is *s2?

also ‘o’ (don’t return 0)

```
char* w = "word1";
char* x = "word2";
```



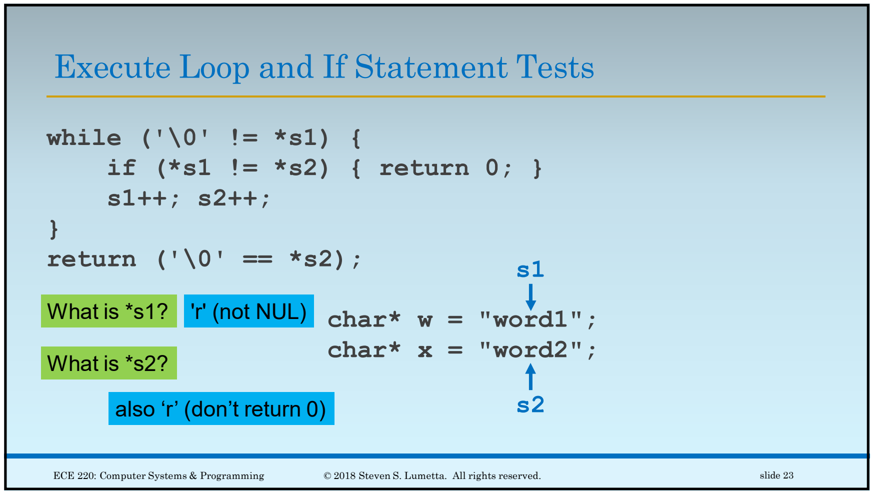
Advance **s1** and **s2** to Point to Next Characters

```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

Advance s1.

And advance s2.

```
char* w = "word1";
char* x = "word2";
```



Execute Loop and If Statement Tests

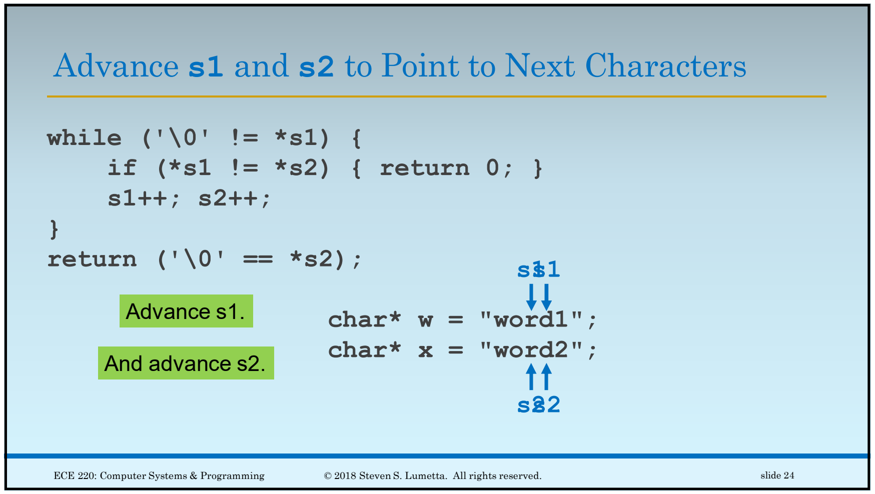
```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

What is *s1? 'r' (not NUL)

What is *s2?

also ‘r’ (don’t return 0)

```
char* w = "word1";
char* x = "word2";
```



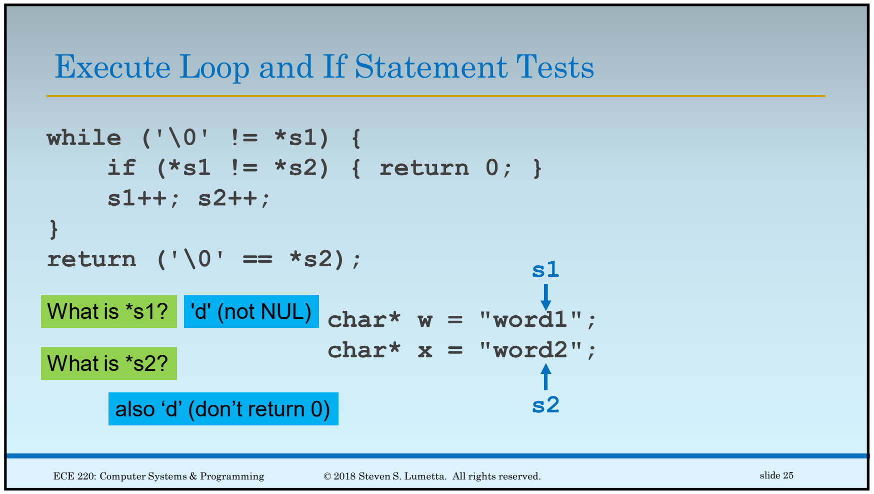
Advance **s1** and **s2** to Point to Next Characters

```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

Advance s1.

And advance s2.

```
char* w = "word1";
char* x = "word2";
```



Execute Loop and If Statement Tests

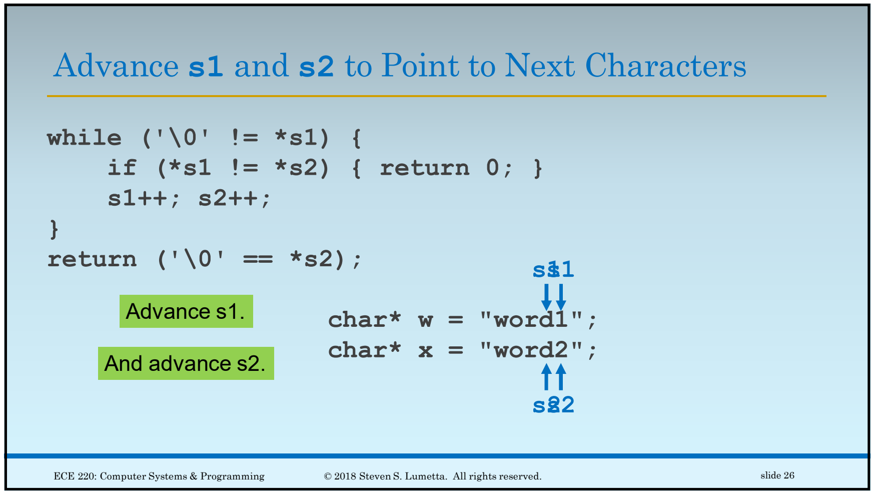
```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

What is *s1? 'd' (not NUL)

What is *s2?

also ‘d’ (don’t return 0)

```
char* w = "word1";
char* x = "word2";
```



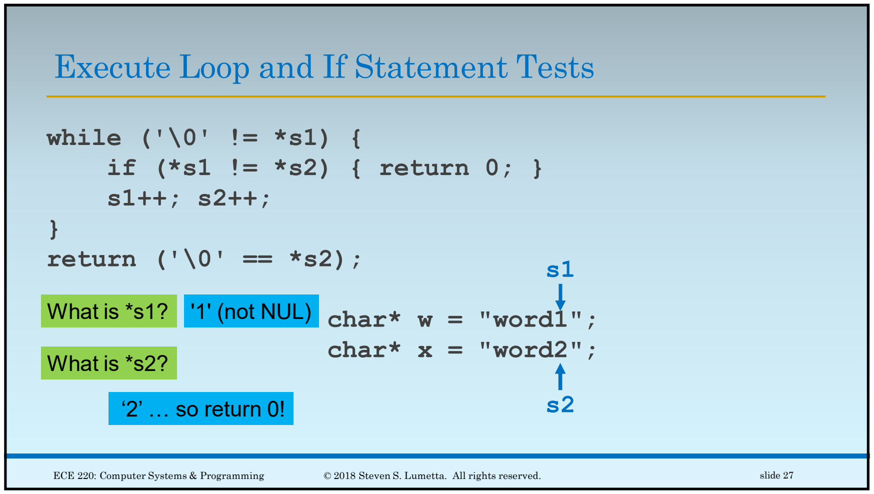
Advance **s1** and **s2** to Point to Next Characters

```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

Advance s1.

And advance s2.

```
char* w = "word1";
char* x = "word2";
```



Execute Loop and If Statement Tests

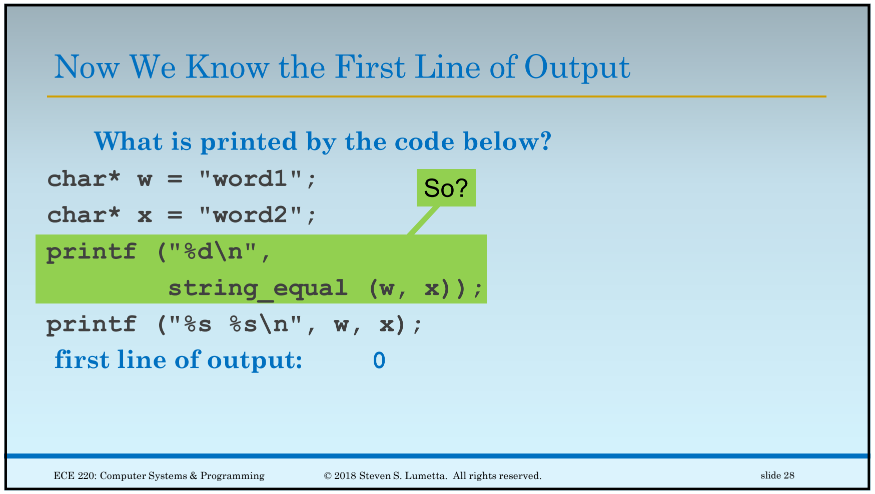
```
while ('\0' != *s1) {
    if (*s1 != *s2) { return 0; }
    s1++; s2++;
}
return ('\0' == *s2);
```

What is *s1? '1' (not NUL)

What is *s2?

‘2’ … so return 0!

```
char* w = "word1";
char* x = "word2";
```



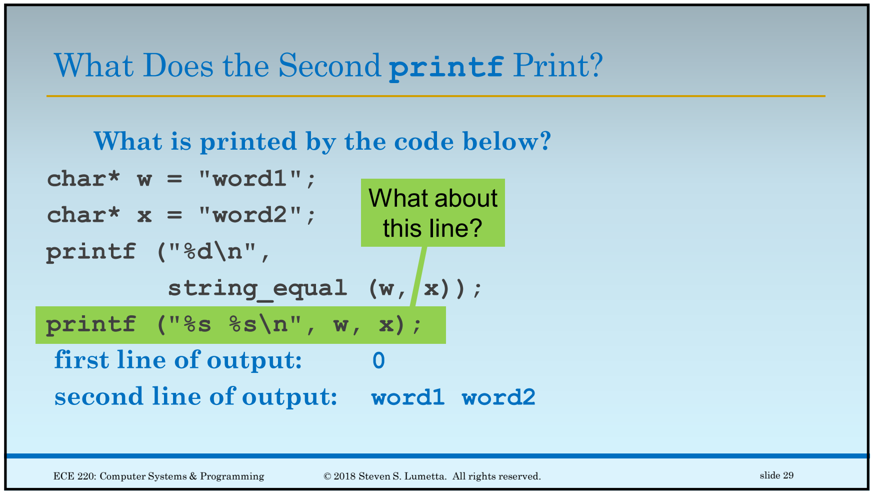
Now We Know the First Line of Output

What is printed by the code below?

```
char* w = "word1";
char* x = "word2";
printf ("%d\n",
        string_equal (w, x));
printf ("%s %s\n", w, x);
```

So?

first line of output: 0



What Does the Second **printf** Print?

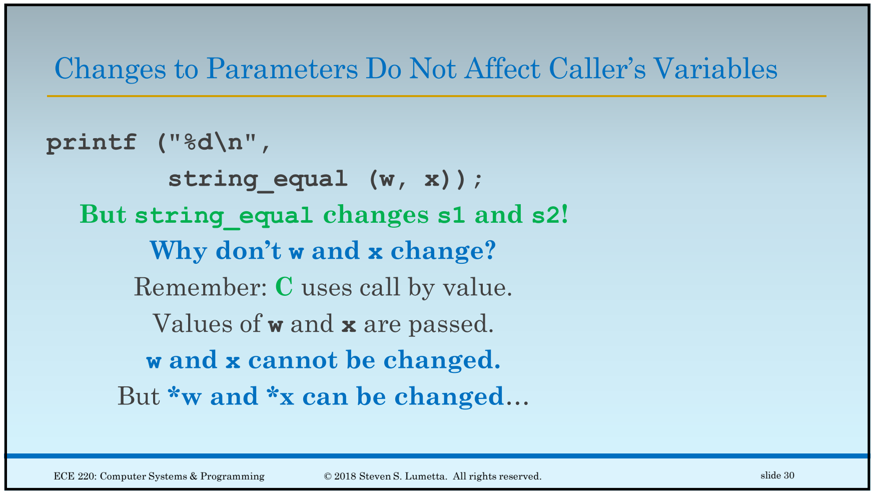
What is printed by the code below?

```
char* w = "word1";
char* x = "word2";
printf ("%d\n",
        string_equal (w, x));
printf ("%s %s\n", w, x);
```

What about this line?

first line of output: 0

second line of output: word1 word2



Changes to Parameters Do Not Affect Caller's Variables

```
printf ("%d\n",
        string_equal (w, x));
```

But string_equal changes s1 and s2!

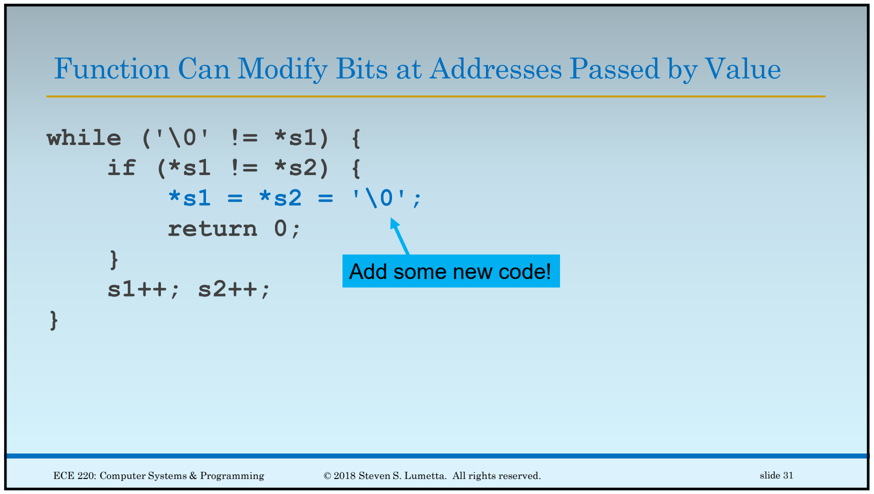
Why don't w and x change?

Remember: **C** uses call by value.

Values of **w** and **x** are passed.

w and x cannot be changed.

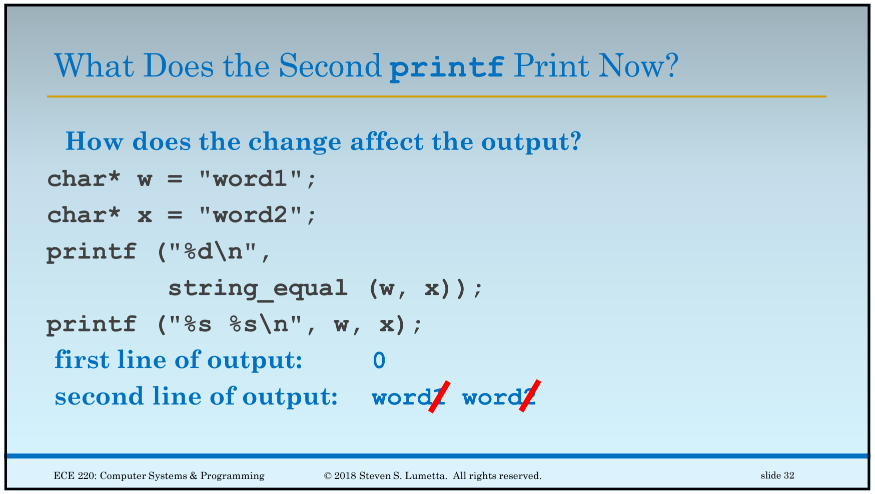
But ***w and *x can be changed…**



Function Can Modify Bits at Addresses Passed by Value

```
while ('\0' != *s1) {
    if (*s1 != *s2) {
        *s1 = *s2 = '\0';
        return 0;
    }
    s1++; s2++;
}
```

Add some new code!



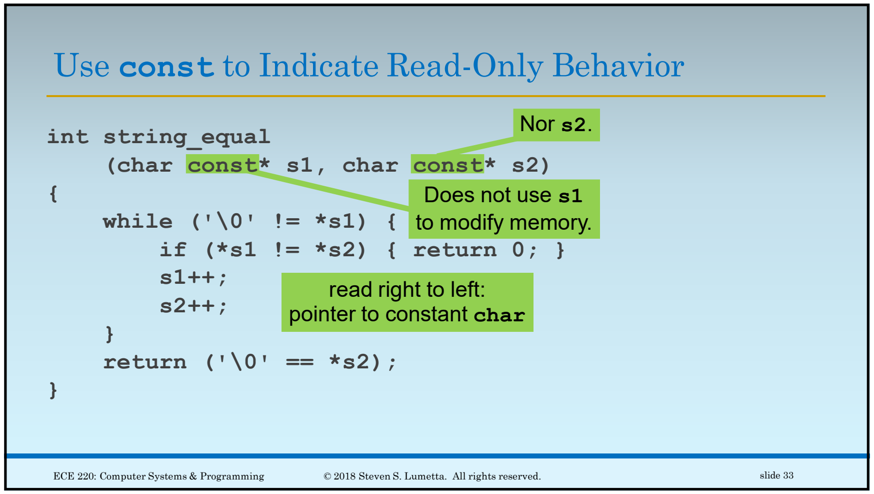
What Does the Second **printf** Print Now?

How does the change affect the output?

```
char* w = "word1";
char* x = "word2";
printf ("%d\n",
        string_equal (w, x));
printf ("%s %s\n", w, x);
```

first line of output: 0

second line of output: word~~1~~ word~~2~~



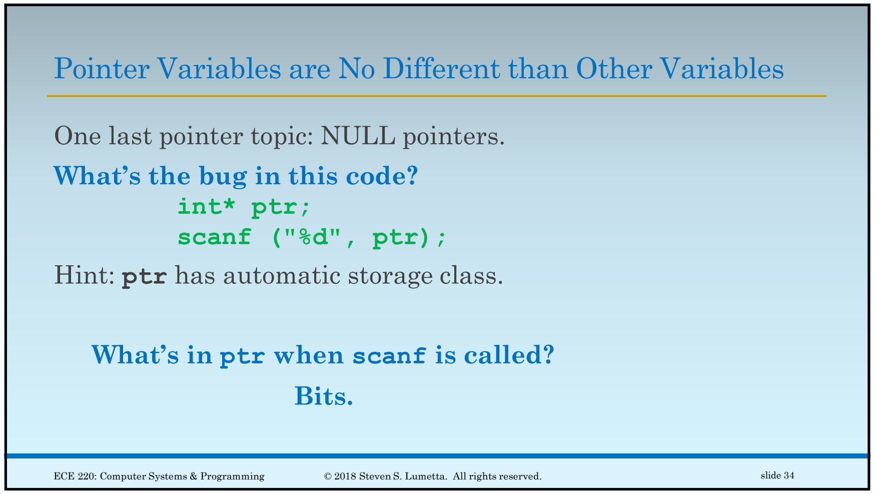
Use **const** to Indicate Read-Only Behavior

```
int string_equal
    (char const* s1, char const* s2)
{
    while ('\0' != *s1) {
        if (*s1 != *s2) { return 0; }
        s1++;
        s2++;
    }
    return ('\0' == *s2);
}
```

Nor **s2**.

Does not use **s1** to modify memory.

read right to left:
pointer to constant **char**



Pointer Variables are No Different than Other Variables

One last pointer topic: NULL pointers.

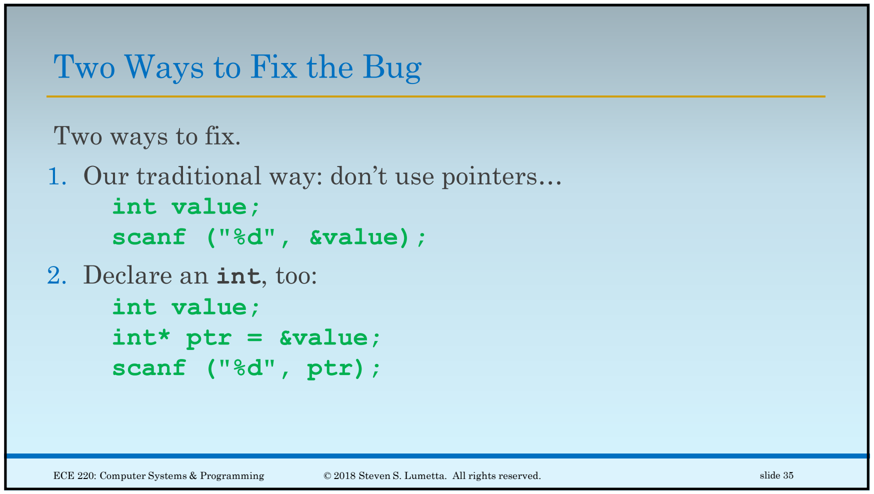
What's the bug in this code?

```
int* ptr;
scanf ("%d", ptr);
```

Hint: **ptr** has automatic storage class.

What's in ptr when scanf is called?

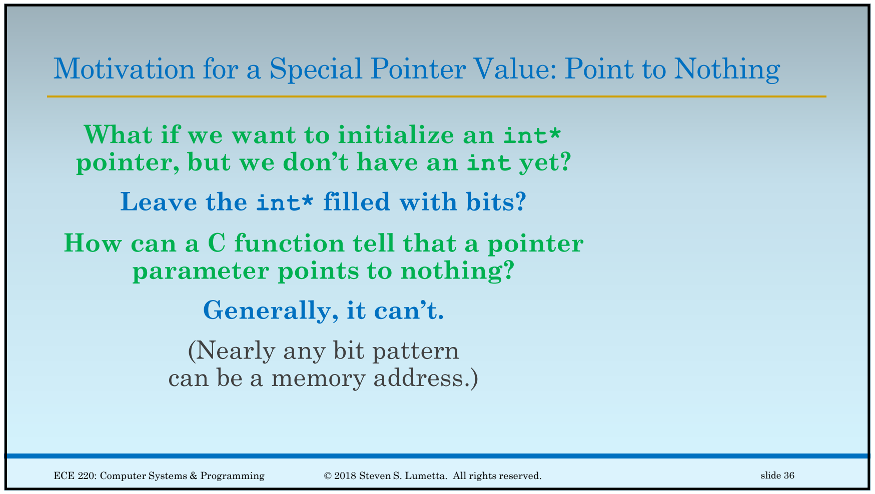
Bits.



Two Ways to Fix the Bug

Two ways to fix.

1. Our traditional way: don't use pointers…
```
int value;
scanf ("%d", &value);
```
2. Declare an **int**, too:
```
int value;
int* ptr = &value;
scanf ("%d", ptr);
```



Motivation for a Special Pointer Value: Point to Nothing

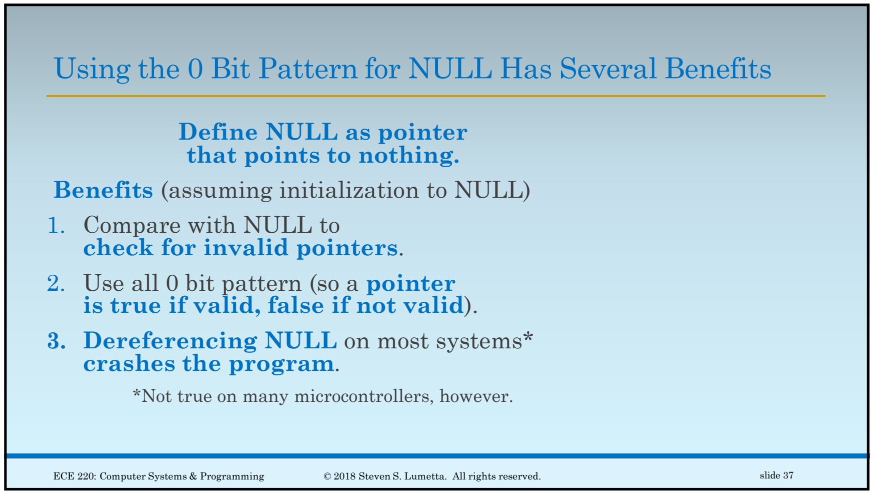
What if we want to initialize an int* pointer, but we don't have an int yet?

Leave the int* filled with bits?

How can a C function tell that a pointer parameter points to nothing?

Generally, it can't.

(Nearly any bit pattern
can be a memory address.)



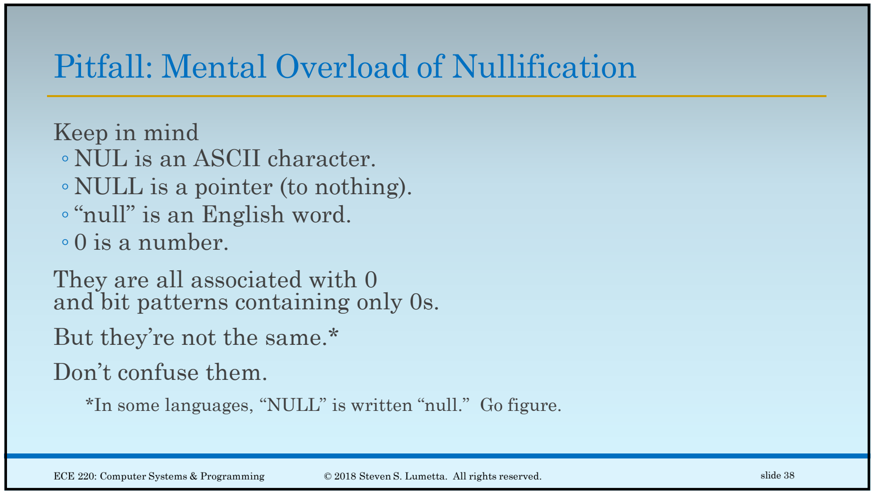
Using the 0 Bit Pattern for NULL Has Several Benefits

Define NULL as pointer that points to nothing.

Benefits (assuming initialization to NULL)

1. Compare with NULL to **check for invalid pointers**.
2. Use all 0 bit pattern (so a **pointer is true if valid, false if not valid**).
3. **Dereferencing NULL** on most systems* **crashes the program**.

*Not true on many microcontrollers, however.



Pitfall: Mental Overload of Nullification

Keep in mind

- NUL is an ASCII character.
- NULL is a pointer (to nothing).
- "null" is an English word.
- 0 is a number.

They are all associated with 0 and bit patterns containing only 0s.

But they're not the same.*

Don't confuse them.

*In some languages, "NULL" is written "null." Go figure.