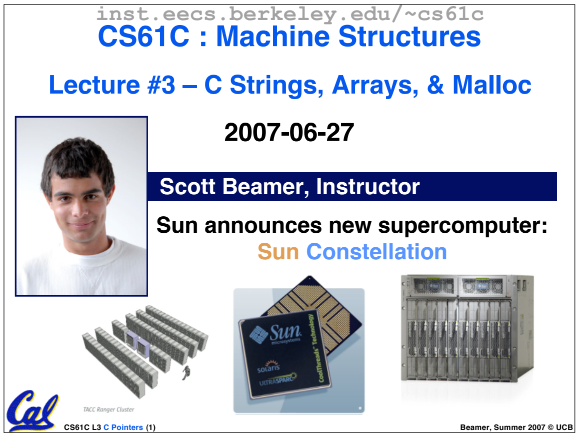

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CS61C : Machine Structures

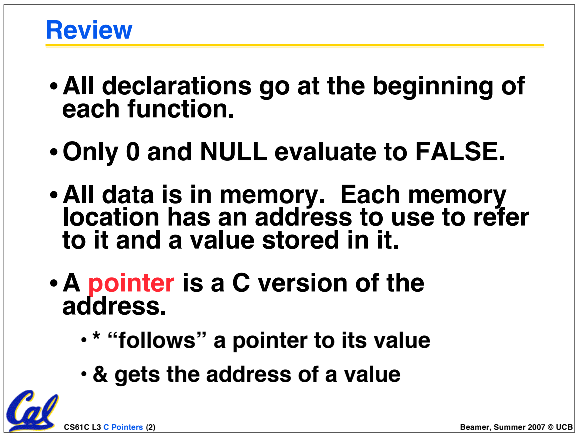
Lecture #3 – C Strings, Arrays, & Malloc

2007-06-27

Scott Beamer, Instructor

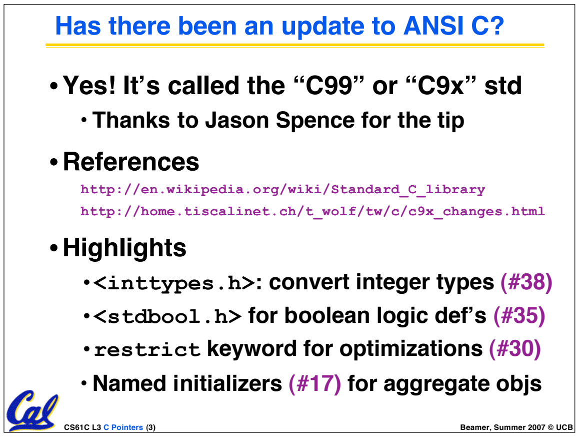
Sun announces new supercomputer:
Sun Constellation

TACC Ranger Cluster



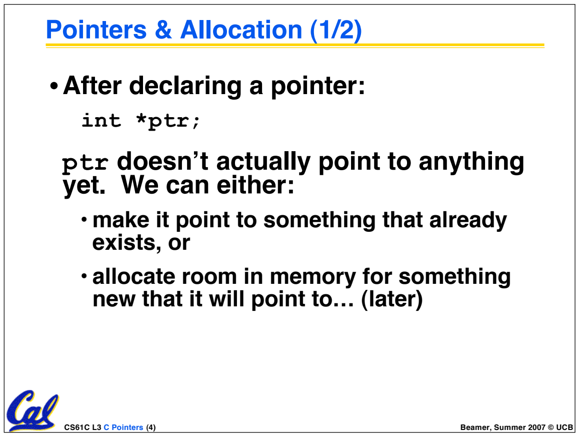
Review

- All declarations go at the beginning of each function.
- Only 0 and NULL evaluate to FALSE.
- All data is in memory. Each memory location has an address to use to refer to it and a value stored in it.
- A pointer is a C version of the address.
  - * "follows" a pointer to its value
  - & gets the address of a value



Has there been an update to ANSI C?

- Yes! It's called the "C99" or "C9x" std
  - Thanks to Jason Spence for the tip
- References
  http://en.wikipedia.org/wiki/Standard_C_library
  http://home.tiscalinet.ch/t_wolf/tw/c/c9x_changes.html
- Highlights
  - `<inttypes.h>`: convert integer types (#38)
  - `<stdbool.h>` for boolean logic def's (#35)
  - `restrict` keyword for optimizations (#30)
  - Named initializers (#17) for aggregate objs



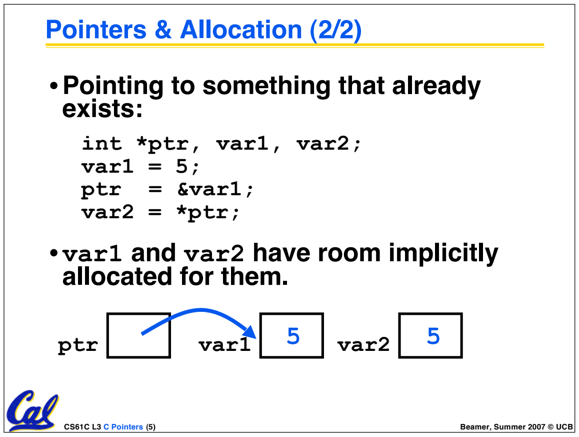
Pointers & Allocation (1/2)

- After declaring a pointer:

```
int *ptr;
```

`ptr` doesn't actually point to anything yet. We can either:

  - make it point to something that already exists, or
  - allocate room in memory for something new that it will point to… (later)



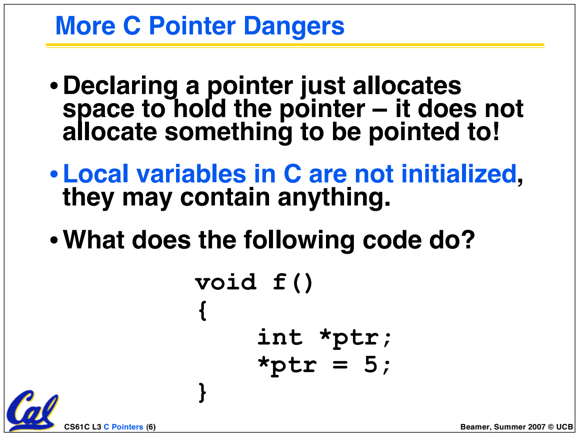
Pointers & Allocation (2/2)

- Pointing to something that already exists:

```
int *ptr, var1, var2;
var1 = 5;
ptr  = &var1;
var2 = *ptr;
```

- `var1` and `var2` have room implicitly allocated for them.

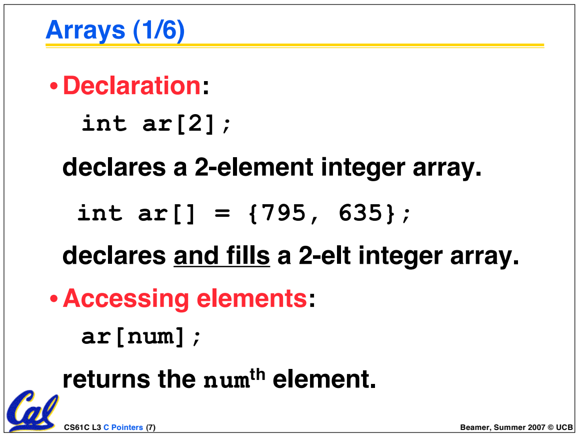
ptr
var1
5
var2
5



More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate something to be pointed to!
- Local variables in C are not initialized, they may contain anything.
- What does the following code do?

```
void f()
{
    int *ptr;
    *ptr = 5;
}
```



Arrays (1/6)

- **Declaration**:

```
int ar[2];
```

declares a 2-element integer array.

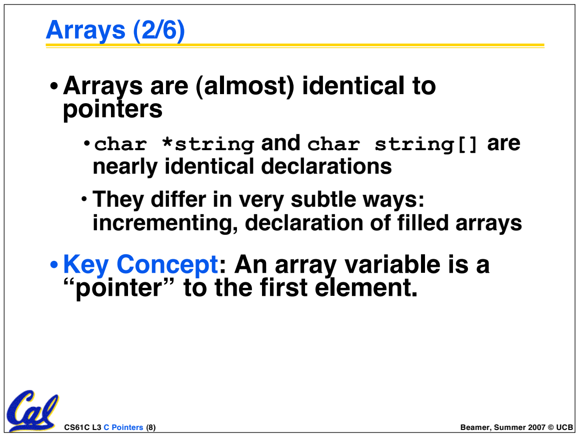
```
int ar[] = {795, 635};
```

declares and fills a 2-elt integer array.

- **Accessing elements**:

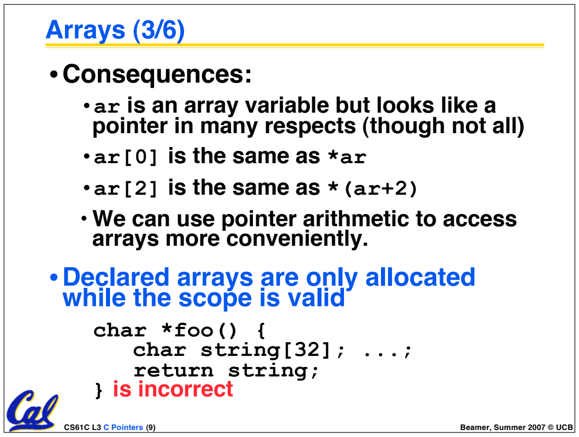
```
ar[num];
```

returns the `num`th element.



Arrays (2/6)

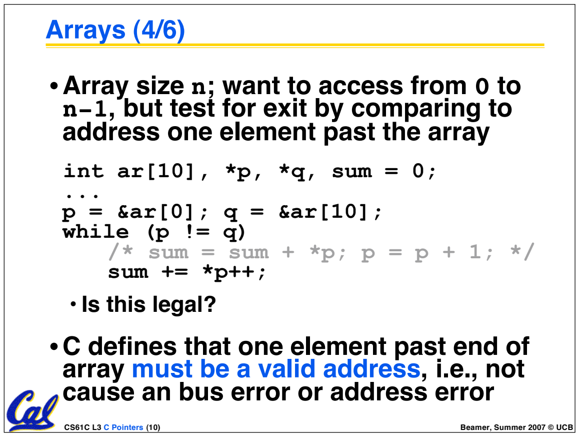
- **Arrays are (almost) identical to pointers**
  - `char *string` and `char string[]` are nearly identical declarations
  - They differ in very subtle ways: incrementing, declaration of filled arrays
- **Key Concept: An array variable is a "pointer" to the first element.**



Arrays (3/6)

- **Consequences:**
  - `ar` is an array variable but looks like a pointer in many respects (though not all)
  - `ar[0]` is the same as `*ar`
  - `ar[2]` is the same as `*(ar+2)`
  - We can use pointer arithmetic to access arrays more conveniently.
- **Declared arrays are only allocated while the scope is valid**

```
char *foo() {
    char string[32]; ...;
    return string;
} is incorrect
```

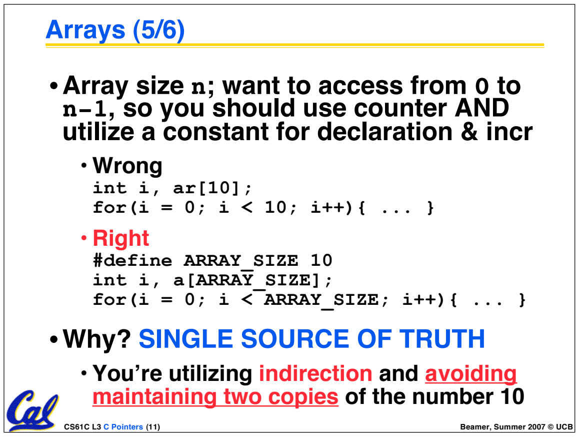


Arrays (4/6)

- **Array size `n`; want to access from `0` to `n-1`, but test for exit by comparing to address one element past the array**

```
int ar[10], *p, *q, sum = 0;
...
p = &ar[0]; q = &ar[10];
while (p != q)
    /* sum = sum + *p; p = p + 1; */
    sum += *p++;
```

  - Is this legal?
- **C defines that one element past end of array must be a valid address, i.e., not cause an bus error or address error**



Arrays (5/6)

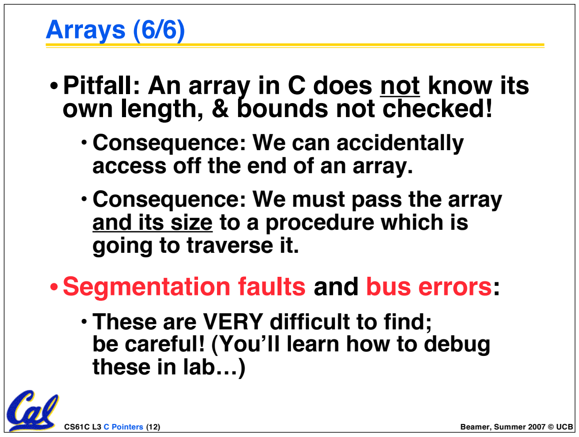
- **Array size `n`; want to access from `0` to `n-1`, so you should use counter AND utilize a constant for declaration & incr**
  - Wrong

```
int i, ar[10];
for(i = 0; i < 10; i++){ ... }
```

  - Right

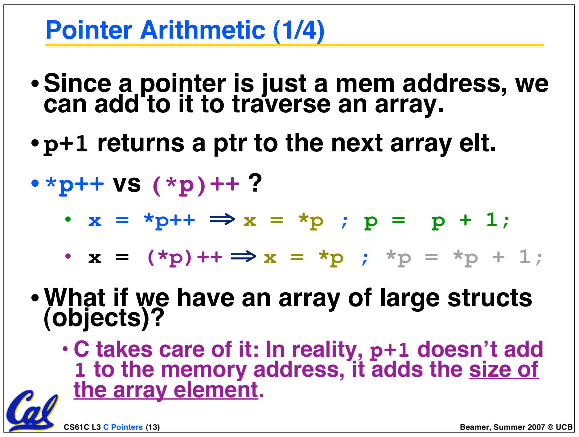
```
#define ARRAY_SIZE 10
int i, a[ARRAY_SIZE];
for(i = 0; i < ARRAY_SIZE; i++){ ... }
```

- **Why? SINGLE SOURCE OF TRUTH**
  - You're utilizing indirection and avoiding maintaining two copies of the number 10



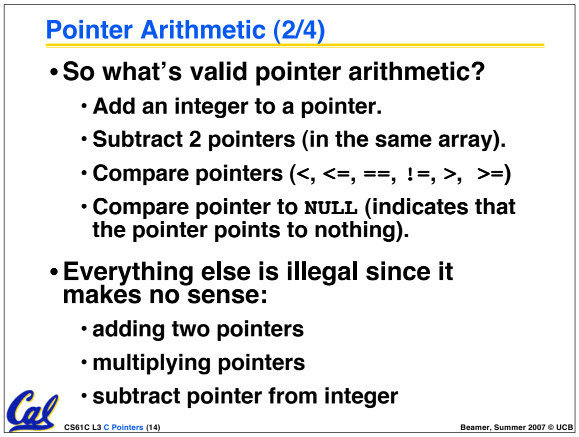
Arrays (6/6)

- **Pitfall: An array in C does not know its own length, & bounds not checked!**
  - Consequence: We can accidentally access off the end of an array.
  - Consequence: We must pass the array and its size to a procedure which is going to traverse it.
- **Segmentation faults and bus errors:**
  - These are VERY difficult to find; be careful! (You'll learn how to debug these in lab…)



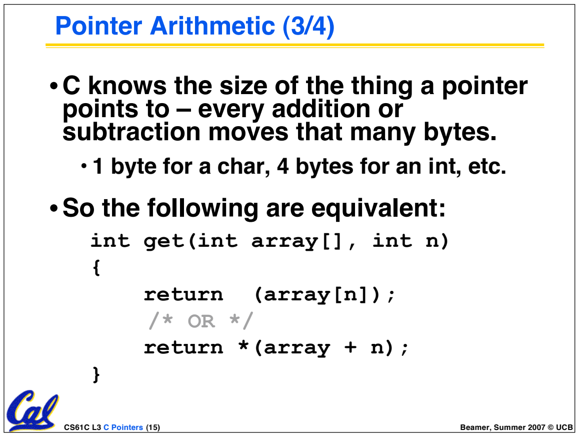
Pointer Arithmetic (1/4)

- Since a pointer is just a mem address, we can add to it to traverse an array.
- `p+1` returns a ptr to the next array elt.
- `*p++` vs `(*p)++` ?
  - `x = *p++` ⇒ `x = *p ; p =  p + 1;`
  - `x = (*p)++` ⇒ `x = *p ; *p = *p + 1;`
- What if we have an array of large structs (objects)?
  - C takes care of it: In reality, `p+1` doesn't add `1` to the memory address, it adds the <u>size of the array element</u>.



Pointer Arithmetic (2/4)

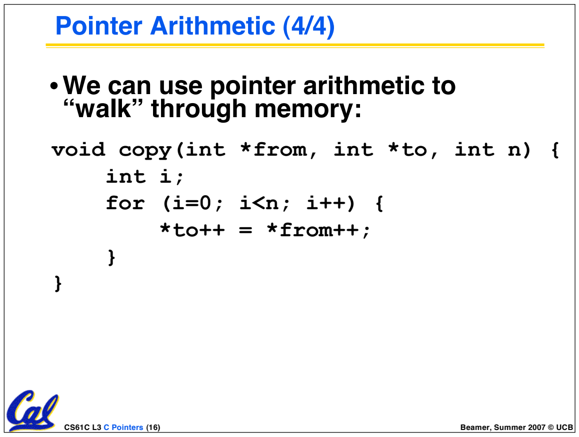
- So what's valid pointer arithmetic?
  - Add an integer to a pointer.
  - Subtract 2 pointers (in the same array).
  - Compare pointers (<, <=, ==, !=, >, >=)
  - Compare pointer to `NULL` (indicates that the pointer points to nothing).
- Everything else is illegal since it makes no sense:
  - adding two pointers
  - multiplying pointers
  - subtract pointer from integer



Pointer Arithmetic (3/4)

- C knows the size of the thing a pointer points to – every addition or subtraction moves that many bytes.
  - 1 byte for a char, 4 bytes for an int, etc.
- So the following are equivalent:

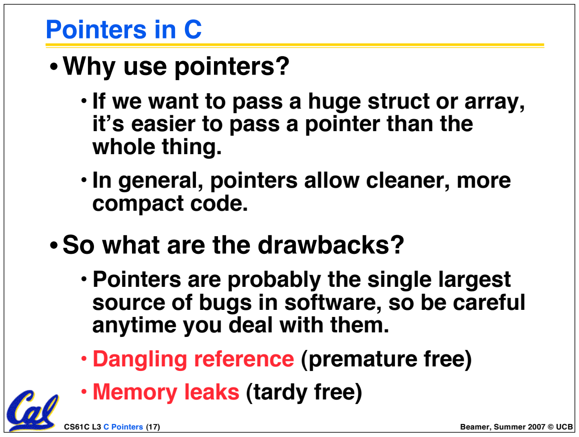
```
int get(int array[], int n)
{
    return  (array[n]);
    /* OR */
    return *(array + n);
}
```



Pointer Arithmetic (4/4)

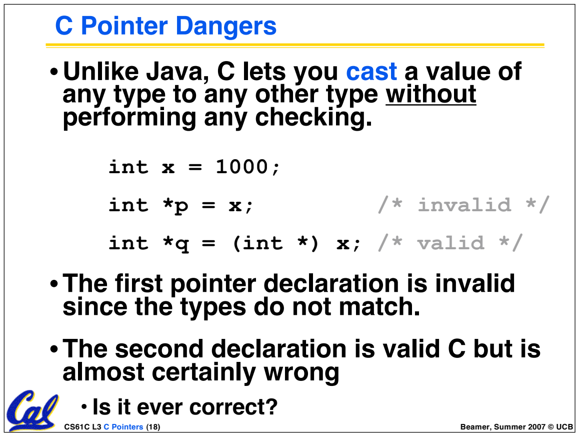
- We can use pointer arithmetic to "walk" through memory:

```
void copy(int *from, int *to, int n) {
    int i;
    for (i=0; i<n; i++) {
        *to++ = *from++;
    }
}
```



Pointers in C

- Why use pointers?
  - If we want to pass a huge struct or array, it's easier to pass a pointer than the whole thing.
  - In general, pointers allow cleaner, more compact code.
- So what are the drawbacks?
  - Pointers are probably the single largest source of bugs in software, so be careful anytime you deal with them.
  - Dangling reference (premature free)
  - Memory leaks (tardy free)



C Pointer Dangers

- Unlike Java, C lets you cast a value of any type to any other type <u>without</u> performing any checking.

```
int x = 1000;
int *p = x;          /* invalid */
int *q = (int *) x;  /* valid */
```

- The first pointer declaration is invalid since the types do not match.
- The second declaration is valid C but is almost certainly wrong
  - Is it ever correct?

Segmentation Fault vs Bus Error?

- `http://www.hyperdictionary.com/`
- Bus Error
  - A fatal failure in the execution of a machine language instruction resulting from the processor detecting an anomalous condition on its bus. Such conditions include invalid address alignment (accessing a multi-byte number at an odd address), accessing a physical address that does not correspond to any device, or some other device-specific hardware error. A bus error triggers a processor-level exception which Unix translates into a "SIGBUS" signal which, if not caught, will terminate the current process.
- Segmentation Fault
  - An error in which a running Unix program attempts to access memory not allocated to it and terminates with a segmentation violation error and usually a core dump.

Administrivia

- Homework expectations
  - Readers don't have time to fix your programs which have to run on lab machines.
  - Code that doesn't compile or fails all of the autograder tests ⇒ 0
- Labs due in lab or by first 10 minutes of next lab
- Worried about getting into the class?

  stick around…

Administrivia

- Slip days
  - You get 2 "slip days" per year to use for any assignment (except the last one of the term)
  - They are used at 1-day increments. Thus 1 *minute* late = 1 slip day used.
  - They're recorded automatically (by checking submission time) so you don't need to tell us when you're using them
  - Once you've used all of your slip days, when a project/hw is late, it's … 0 points.
  - If you submit twice, we ALWAYS grade the latter, and deduct slip days appropriately
  - You no longer need to tell anyone how your dog ate your computer.
  - You should really save for a rainy day … we all get sick and/or have family emergencies!

C Strings

- A string in C is just an array of characters.

```
char string[] = "abc";
```

- How do you tell how long a string is?
  - Last character is followed by a 0 byte (null terminator)

```
int strlen(char s[])
{
    int n = 0;
    while (s[n] != 0) n++;
    return n;
}
```

Arrays vs. Pointers

- An array name is a read-only pointer to the 0th element of the array.
- An array parameter can be declared as an array <u>or</u> a pointer; an array argument can be passed as a pointer.

```
int strlen(char s[])          int strlen(char *s)
{                             {
    int n = 0;                    int n = 0;
    while (s[n] != 0)             while (s[n] != 0)
        n++;                          n++;
    return n;                     return n;
}                             }
```

Could be written:
`while (s[n])`

C Strings Headaches

- One common mistake is to forget to allocate an extra byte for the null terminator.
- More generally, C requires the programmer to manage memory manually (unlike Java or C++).
  - When creating a long string by concatenating several smaller strings, the programmer must insure there is enough space to store the full string!
  - What if you don't know ahead of time how big your string will be?
  - Buffer overrun security holes!

Common C Errors

- There is a difference between assignment and equality
  - `a = b` is assignment
  - `a == b` is an equality test
- This is one of the most common errors for beginning C programmers!

Pointer Arithmetic Peer Instruction Q

How many of the following are invalid?

I. pointer + integer
II. integer + pointer
III. pointer + pointer
IV. pointer – integer
V. integer – pointer
VI. pointer – pointer
VII. compare pointer to pointer
VIII. compare pointer to integer
IX. compare pointer to 0
X. compare pointer to `NULL`

`#invalid`
1
2
3
4
5
6
7
8
9
`(1)` 0

Pointer Arithmetic Peer Instruction Ans

- How many of the following are invalid?

I.	pointer + integer	ptr + 1
II.	integer + pointer	1 + ptr
III.	pointer + pointer	ptr + ptr
IV.	pointer – integer	ptr - 1
V.	integer – pointer	1 - ptr
VI.	pointer – pointer	ptr - ptr
VII.	compare pointer to pointer	ptr1 == ptr2
VIII.	compare pointer to integer	ptr == 1
IX.	compare pointer to 0	ptr == NULL
X.	compare pointer to NULL	ptr == NULL

`#invalid`
1
2
[✓ 3]
4
5
6
7
8
9
`(1)` 0

Pointer Arithmetic Summary

- `x = *(p+1)` ?
  - ⇒ `x = *(p+1) ;`
- `x = *p+1` ?
  - ⇒ `x = (*p) + 1 ;`
- `x = (*p)++` ?
  - ⇒ `x = *p ; *p = *p + 1;`
- `x = *p++` ? `(*p++)` ? `*(p)++` ? `*(p++)` ?
  - ⇒ `x = *p ; p = p + 1;`
- `x = *++p` ?
  - ⇒ `p = p + 1 ; x = *p ;`
- Lesson?
  - Using anything but the standard `*p++` , `(*p)++` causes more problems than it solves!

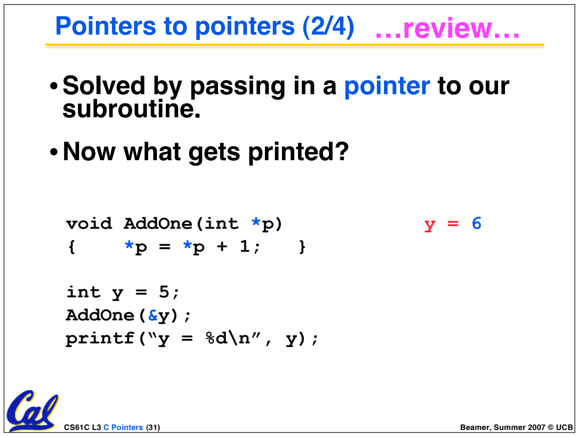
C String Standard Functions

- `int strlen(char *string);`
  - compute the length of `string`
- `int strcmp(char *str1, char *str2);`
  - return 0 if `str1` and `str2` are identical (how is this different from `str1 == str2`?)
- `char *strcpy(char *dst, char *src);`
  - copy the contents of string `src` to the memory at `dst`. The caller must ensure that `dst` has enough memory to hold the data to be copied.

Pointers to pointers (1/4) …review…

- Sometimes you want to have a procedure increment a variable?
- What gets printed?

```
void AddOne(int  x)                y = 5
{     x =  x + 1;    }

int y = 5;
AddOne( y);
printf("y = %d\n", y);
```

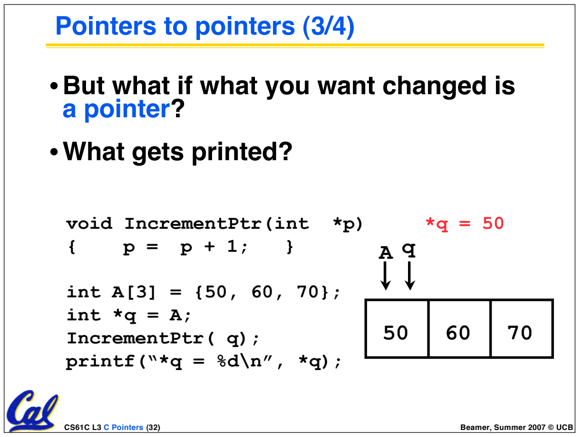


Pointers to pointers (2/4) …review…

- Solved by passing in a pointer to our subroutine.
- Now what gets printed?

```
void AddOne(int *p)
{    *p = *p + 1;    }

int y = 5;
AddOne(&y);
printf(“y = %d\n”, y);
```

y = 6

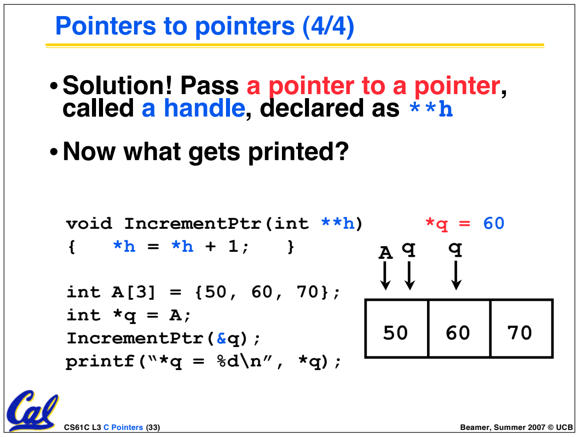


Pointers to pointers (3/4)

- But what if what you want changed is a pointer?
- What gets printed?

```
void IncrementPtr(int  *p)
{    p =  p + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( q);
printf(“*q = %d\n”, *q);
```

*q = 50

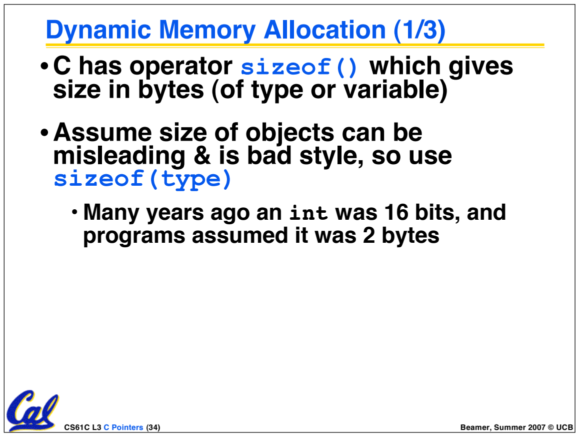


Pointers to pointers (4/4)

- Solution! Pass a pointer to a pointer, called a handle, declared as **h
- Now what gets printed?

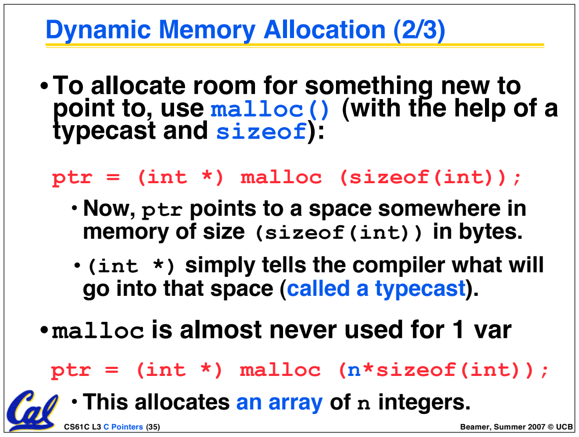
```
void IncrementPtr(int **h)
{   *h = *h + 1;   }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr(&q);
printf(“*q = %d\n”, *q);
```

*q = 60



Dynamic Memory Allocation (1/3)

- C has operator `sizeof()` which gives size in bytes (of type or variable)
- Assume size of objects can be misleading & is bad style, so use `sizeof(type)`
  - Many years ago an `int` was 16 bits, and programs assumed it was 2 bytes



Dynamic Memory Allocation (2/3)

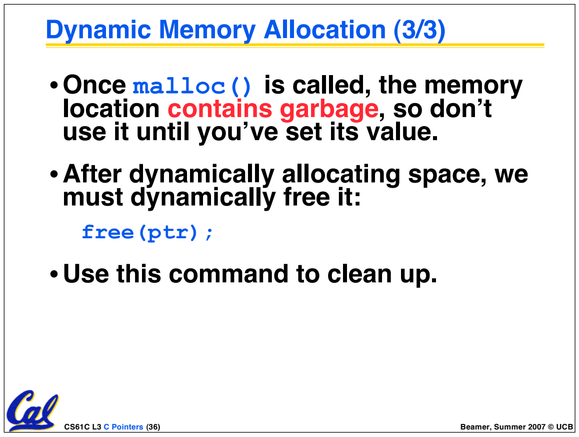
- To allocate room for something new to point to, use `malloc()` (with the help of a typecast and `sizeof`):

```
ptr = (int *) malloc (sizeof(int));
```

  - Now, `ptr` points to a space somewhere in memory of size `(sizeof(int))` in bytes.
  - `(int *)` simply tells the compiler what will go into that space (called a typecast).
- `malloc` is almost never used for 1 var

```
ptr = (int *) malloc (n*sizeof(int));
```

  - This allocates an array of `n` integers.



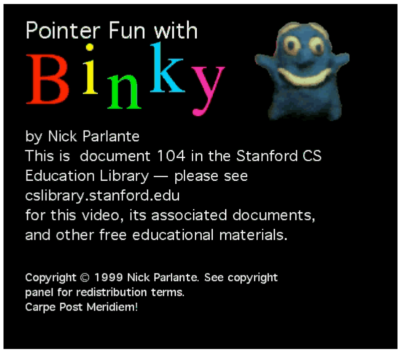
Dynamic Memory Allocation (3/3)

- Once `malloc()` is called, the memory location contains garbage, so don’t use it until you’ve set its value.
- After dynamically allocating space, we must dynamically free it:

```
free(ptr);
```

- Use this command to clean up.

Binky Pointer Video (thanks to NP @ SU)



Pointer Fun with

Binky

by Nick Parlante
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Carpe Post Meridiem!

“And in Conclusion…”

- C99 is the update to the language
- Pointers and arrays are virtually same
- C knows how to increment pointers
- C is an efficient language, with little protection
  - Array bounds not checked
  - Variables not automatically initialized
- (Beware) The cost of efficiency is more overhead for the programmer.
  - “C gives you a lot of extra rope but be careful not to hang yourself with it!”
- Use handles to change pointers