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# CS61C : Machine Structures

## Lecture 4 – Introduction to C (pt 2)

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C review update: Tonight 7:30-8:30pm @ 306 Soda

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**All eyes on Apple ⇒**
Today, Apple will make a big announcement; many have speculated it's a "tablet" (much like the iPhone) which will change the industry.

www.nytimes.com/2010/01/26/technology/26apple.html



## Review

- All declarations go at the beginning of each function except if you use C99.
- 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



## 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 (1/5)

- Declaration:

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

declares a 2-element integer array. *An array is really just a block of memory.*

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

declares and fills a 2-elt integer array.

- Accessing elements:

```
ar[num]
```

returns the `num`th element.



## Arrays (2/5)

- 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 (3/5)

- 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 (4/5)

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

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

  - Right

```
int 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 (5/5)

- 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 (1/2)

- 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 size of the array element.



## Pointer Arithmetic (2/2)

- 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);
}
```



## Pointers in C

- Why use pointers?
  - If we want to pass a huge struct or array, it's easier / faster / etc 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 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;
}
```

## Pointer Arithmetic Peer Instruction Q

How many of the following are invalid?

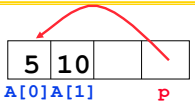
I. pointer + integer
II. integer + pointer
III. pointer + pointer
IV. pointer – integer
V. integer – pointer
VI. pointer – pointer
VII. compare pointer to pointer
VIII. compare pointer to integer
IX. compare pointer to 0
X. compare pointer to NULL

| #invalid |
|---|
| a) 1 |
| b) 2 |
| c) 3 |
| d) 4 |
| e) 5 |



## Peer Instruction

```
int main(void){
 int A[] = {5,10};
 int *p = A;
 printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  p = p + 1;
 printf("%u %d %d %d\n",p,*p,A[0],A[1]);
 *p = *p + 1;
 printf("%u %d %d %d\n",p,*p,A[0],A[1]);
 }
```




If the first `printf` outputs `100 5 5 10`, what will the other two `printf` output?

a) 101 10 5 10 then 101 11 5 11
b) 104 10 5 10 then 104 11 5 11
c) 101 <other> 5 10 then 101 <3-others>
d) 104 <other> 5 10 then 104 <3-others>
e) One of the two printfs causes an ERROR



## "And in Conclusion…"

- 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!"



## Reference slides

You ARE responsible for the material on these slides (they're just taken from the reading anyway) ; we've moved them to the end and off-stage to give more breathing room to lecture!



## Administrivia

- Read K&R 6 by the next lecture
- There is a language called D!
  - www.digitalmars.com/d/
- 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



## Administrivia

- Slip days
  - You get 3 "slip days" per year to use for any homework assignment or project
  - 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!

## Pointers & Allocation (1/2)

- After declaring a pointer:

```
int *ptr;
```

`ptr` doesn't actually point to anything yet *(it actually points somewhere - but don't know where!)*. We can either:

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

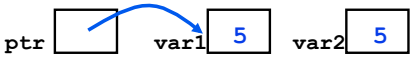


## Pointers & Allocation (2/2)

- 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.






## Arrays (one elt past array must be valid)

- 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



## Pointer Arithmetic

- 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 to Copy memory

- 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++;
    }
}
```

- Note we had to pass size (`n`) to `copy`



## 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 or a pointer; an array argument can be passed as a pointer.

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

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

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

## 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!



## 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.



## C Pointer Dangers

- Unlike Java, C lets you cast a value of any type to any other type without 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?



## 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 Error

- 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!
  - One solution (when comparing with constant) is to put the var on the right! If you happen to use =, it won't compile.

```
if (3 == a) { ...
```



## 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.