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CS61C : Machine Structures

Lecture #3 – C Pointers

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There is one handout today at the front and back of the room!

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Paper display! ⇒ Philips Polymer Vision has demonstrated a prototype "rollable, paper-like display: Readius. Cool!

www.polymervision.com

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:

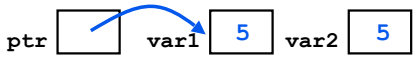
- make it point to something that already exists, or
- allocate room in memory for something new that it will point to… (later)

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.



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 size of the array element.

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 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?

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

- Read K&R 6 by the next lecture
- There is a language called D!
  - www.digitalmars.com/d/
- Answers to the reading quizzes?
  - Ask your TA in discussion
- 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!

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 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])
```

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?

		#invalid
I.	pointer + integer	1
II.	integer + pointer	2
III.	pointer + pointer	3
IV.	pointer – integer	4
V.	integer – pointer	5
VI.	pointer – pointer	6
VII.	compare pointer to pointer	7
VIII.	compare pointer to integer	8
IX.	compare pointer to 0	9
X.	compare pointer to NULL	(1) 0

Kilo, Mega, Giga, Tera, Peta, Exa, Zetta, Yotta

1. Kim's melodious giddiness terrifies people, excepting zealous yodelers
2. Kirby Messed Gigglypuff Terribly, (then) Perfectly Exterminated Zelda and Yoshi
3. Killed meat gives teeth peace except zebra yogurt
4. Kind Men Give Tense People Extra Zeal (for) Yoga
5. Killing melee gives terror; peace exhibits Zen yoga
6. Killing messengers gives terrible people exactly zero, yo
7. Kindergarten means giving teachers perfect examples (of) zeal (&) youth
8. Kissing mediocre girls/guys teaches people (to) expect zero (from) you
9. Kinky Mean Girls Teach Penis-Extending Zen Yoga
10. Kissing Mel Gibson, Teddy Pendergrass exclaimed: "Zesty, yo!"

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)
{     x =  x + 1;   }

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

y = 5

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

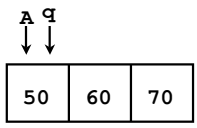
Pointers to pointers (3/4)

- 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



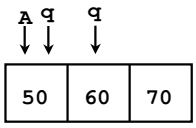
Pointers to pointers (4/4)

- 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.

"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