CS 61C: Great Ideas in Computer Architecture Introduction to C, Part II

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Agenda

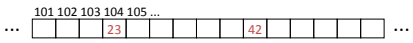
- Review
- Pointers
- Administrivia
- Arrays
- Technology Break
- Summary

Review

- C is a popular and efficient compiled language used for systems programming and application development
  - Derivatives include C++, Objective-C, C#
  - Java borrowed much of the basic syntax
- Very close to machine, so sometimes difficult to program and debug
- Key concepts last time: compilation, preprocessor, typed data and functions, main(), structs, enums, control flow

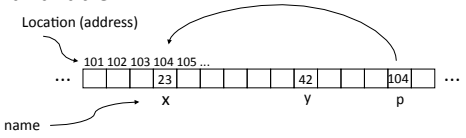
Address vs. Value

- Consider memory to be a single huge array
  - Each cell of the array has an address associated with it
  - Each cell also stores some value
  - Do you think they use signed or unsigned numbers? Negative address?!
- Don't confuse the address referring to a memory location with the value stored there



Pointers

- An *address* refers to a particular memory location; e.g., it points to a memory location
- *Pointer*: A variable that contains the address of a variable



Pointer Syntax

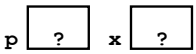
- `int *x;`
  - Tells compiler that variable x is address of an `int`
- `x = &y;`
  - Tells compiler to assign address of `y` to `x`
  - `&` called the "address operator" in this context
- `z = *x;`
  - Tells compiler to assign value at address in `x` to `z`
  - `*` called the "dereference operator" in this context

Creating and Using Pointers

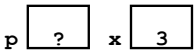
- How to create a pointer:

  & operator: get address of a variable

```
int *p, x;
```




```
x = 3;
```




```
p = &x;
```

Note the "*" gets used 2 different ways in this example. In the declaration to indicate that **p** is going to be a pointer, and in the **printf** to get the value pointed to by **p**.

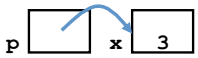
- How get a value pointed to?

  "*" (dereference operator): get the value that the pointer points to

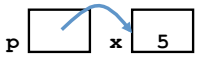
```
printf("p points to %d\n",*p);
```


Using Pointer for Writes

- How to change a variable pointed to?
  - Use the dereference operator * on left of assignment operator =




```
*p = 5;
```



Pointers and Parameter Passing

- Java and C pass parameters "by value"
  - Procedure/function/method gets a copy of the parameter, *so changing the copy cannot change the original*

```
void addOne (int x) {
   x = x + 1;
 }
int y = 3;
addOne(y);
```

y remains equal to 3

Pointers and Parameter Passing

- How can we get a function to change the value held in a variable?

```
void addOne (int *p) {
   *p = *p + 1;
 }
int y = 3;

addOne(&y);
```

y is now equal to 4

Types of Pointers

- Pointers are used to point to any kind of data (**int**, **char**, a **struct**, etc.)
- Normally a pointer only points to one type (**int**, **char**, a **struct**, etc.).
  - **void *** is a type that can point to anything (generic pointer)
  - Use sparingly to help avoid program bugs, and security issues, and other bad things!

More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate the thing being pointed to!
- Local variables in C are not initialized, they may contain anything (aka "garbage")
- What does the following code do?

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

Pointers and Structures

```
struct Point {
    int x;
    int y;
};

Point p1;
Point p2;
Point *paddr;
```

```
/* dot notation */
int h = p1.x;
p2.y = p1.y;

/* arrow notation */
int h = paddr->x;
int h = (*paddr).x;

/* This works too */
p1 = p2;
```


Pointers in C

- Why use pointers?
  - If we want to pass a large 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 C, so be careful anytime you deal with them
    - Most problematic with dynamic memory management—which you will to know by the end of the semester, but not for the projects (there will be a lab later in the semester)
    - *Dangling references* and *memory leaks*

Why Pointers in C?

- At time C was invented (early 1970s), compilers often didn't produce efficient code
  - Computers 25,000 times faster today, compilers better
- C designed to let programmer say what they want code to do without compiler getting in way
  - Even give compilers hints which registers to use!
  - Still useful for low-level system code
- Today's compilers produce much better code, so may not need to use pointers
  - Compilers even ignore hints since they do it better!

How many logic and syntax errors?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ ≥4

```
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 1;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,p);
}
flip-sign(int *n){*n = -(*n)}
```


Peer Instruction Answer

```
#insert <stdio.h>
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 1;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,*p);
}
flip-sign(int *n){*n = -(*n);}
```

5 syntax + logic errors in this C code

What is output after correct errors?

- ☐ x=5,y=6,p=-5
- ☐ x=-5,y=6,p=-5
- ☐ x=-5,y=4,p=-5
- ☐ x=-5,y=-6,p=-5

```
void main(); {
  int *p, x=5, y; // init
  int z;
  y = *(p = &x) + 1;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",
   x,y,*p);
}
flip-sign(int *n)
   {*n = -(*n); }
```

Administrivia

- HW #2
- Lab #2
- No Discussion sections this week, but extra office hours…

Extra Office Hours This Week

(Alan Christopher: Tue 5-7 320 Soda)
Loc Do: Fri 12-2pm Qualcomm Cyber Café
(James Ferguson: Tue 10-11 AM & 1-2 PM, 320 Soda)
Anirudh Garg: Wed 4-6 Qualcomm Cyber Café
William Ku: 6-8 Thursday 283E Soda
Brandon Luong: Wed 6-8 283E Soda
Ravi Punj: Wed 12-2 Free Speech Movement Cafe.
Sung Roa Yoon: Thu 7-9 283E Soda.

Watch Piazza!

The Rules (and we really mean it!)

Arrays (1/5)

- Declaration:
  `int ar[2];`
  declares a 2-element integer array: just a block of memory

  `int ar[] = {795, 635};`
  declares and initializes a 2-element integer array

- Accessing elements:
  `ar[num]`
  returns the numth element

Arrays (2/5)

- C arrays are (almost) identical to pointers
  - **`char *string`** and **`char string[]`** are nearly identical declarations
  - Differ in subtle ways: incrementing, declaration of filled arrays
  - End of C string marked by 0 in last character
- *Key Concept*: Array variable is a "pointer" to the first (0th) element

C Strings

- 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 (aka "null terminator")

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

Arrays (3/5)

- Consequences:
  - `ar` is an array variable, but looks like a pointer
  - `ar[0]` is the same as `*ar`
  - `ar[2]` is the same as `*(ar+2)`
  - We can use pointer arithmetic to conveniently access arrays
- Declared arrays are only allocated while the scope is valid

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

is incorrect ***and very very bad***

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 & incrementation
  - Bad pattern

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

  - Better pattern

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

- SINGLE SOURCE OF TRUTH
  - You're utilizing indirection and avoiding maintaining two copies of the number 10
  - DRY: "Don't Repeat Yourself"

Arrays (5/5)

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

Array Summary

- Array indexing is syntactic sugar for pointers
- `a[i]` is treated as `*(a+i)`
- E.g., three equivalent ways to zero an array:
  - `for (i=0; i < size; i++) a[i] = 0;`
  - `for (i=0; i < size; i++) *(a+i) = 0;`
  - `for (p=a; p < a+size; p++) *p = 0;`

Incrementing a pointer makes it point to the next variable in memory (type of pointer says how big each variable is)

What is TRUE about this function?

```
void foo(char *s, char *t)
{ while (*s)
    s++;
  while (*s++ = *t++)
    ;
}
```

- ☐ It has syntax errors
- ☐ No syntax errors; it changes characters in string `t` to next character in the string `s`
- ☐ No syntax errors; it copies a string at address `t` to the string at address `s`
- ☐ No syntax errors; it appends the string at address `t` to the end of the string at address `s`

Question: Which statement is FALSE regarding C and Java?

- ☐ Arrays in C are just pointers to the 0-th element
- ☐ As Java was derived from C, it has the same control flow constructs
- ☐ Like Java, in C you can check the length of an array (`a.length` gives no. elements in `a`)
- ☐ C has pointers but Java does not allow you to manipulate pointers or memory addresses of any kind

FYI—Update to ANSI C

- "C99" or "C9X" standard
  - **`gcc -std=c99`** to compile
- References
  - http://en.wikipedia.org/wiki/C99
  - http://home.tiscalinet.ch/t_wolf/tw/c/c9x_changes.html
- Highlights
  - Declarations in for loops, like Java
  - Java-like // comments (to end of line)
  - Variable-length non-global arrays
  - `<inttypes.h>`: explicit integer types
  - `<stdbool.h>`: for boolean logic types and definitions

And In Conclusion, …

- All data is in memory
  - Each memory location has an address to use to refer to it and a value stored in it
- Pointer is a C version (abstraction) of a data address
  - `*` "follows" a pointer to its value
  - `&` gets the address of a value
  - Arrays and strings are implemented as variations on pointers
- C is an efficient language, but leaves safety to the programmer
  - Array bounds not checked
  - Variables not automatically initialized
  - Use pointers with care: they are a common source of bugs in programs