CSE 374
Programming Concepts & Tools

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(Thanks to Hal Perkins)

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Lecture 7 – Introduction to C: The C Level of Abstraction

Welcome to C

Compared to Java, in rough order of importance

- Lower level (less for compiler to do)
- Unsafe (wrong programs might do anything)
- Procedural programming — not “object-oriented”
- “Standard library” is much smaller
- Many similar control constructs (loops, ifs, ...)
- Many syntactic similarities (operators, types, ...)

• A different world-view and much more to keep track of; Java-like thinking can get you in trouble

Our plan

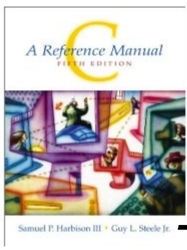
A semi-nontraditional way to learn C:

- Learn how C programs run on typical x86 machines
  - Not promised by C's definition
  - You do *not* need to "reason in terms of the implementation" when you follow the rules
  - But it does help to know this model
    - To remember why C has the rules it does
    - To debug incorrect programs
- Learn some C basics (including "Hello World!")
- Learn what C is (still) used for
- Learn more about the language and good idioms
- Towards the end of the quarter: A little C++

Some references

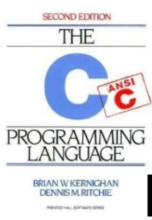
There’s a lot on the web, but here are some primary sources

C: A Reference Manual, Harbison & Steele (now 5th ed.)



- The best current reference on C and its libraries; includes information about recent versions of the C standard

The C Programming Language, Kernighan & Ritchie



- “K&R” is a classic, one that every programmer must read. A bit dated now (doesn’t include C99 or C11 extensions), but the primary source

Essential C, Stanford CS lib,

http://cslibrary.stanford.edu/101/EssentialC.pdf

(on our C Resources page)
Good short introduction to the language

Address space

Simple model of a running process (provided by the OS):

- There is one address space (an array of bytes)
  - Most common size today for a typical machine is 2^{32} or 2^{64}
  - For most of what we do it doesn't matter
  - 2^{64} is way more RAM than you have, you might have 2^{32} (4GB) or more (OS maintains illusion that all processes have this much even if they don't – may lead to slowness)
  - "Subscripting" this array takes 32 or 64 bits
  - Something's address is its position in this array
  - Trying to read a not-used part of the array may cause a "**segmentation fault**" (immediate crash)
- All data and code for the process are in this address space
  - Code and data are bits; program "remembers" what is where
  - O/S also lets you read/write files (stdin, stdout, stderr, etc.)

Address-space layout

- The following can be different on different systems, but it's one way to understand how C is implemented:

	code	globals	heap →	…	← stack

- So in one array of 8-bit bytes we have:
  - Code instructions (typically immutable)
  - Space for global variables (mutable and immutable) (like Java's static fields)
  - A *heap* for other data (like objects returned by Java's new)
  - Unused portions; access causes a "seg-fault"
  - A call-*stack* holding local variables and *code addresses*
- ints typically occupy 4 bytes (32 bits); pointers 4 or 8 (32 or 64) depending on underlying processor/OS (64 on our machines)

The stack

- The **call-stack** (or just stack) has one “part” or “frame” (compiler folks call it an *activation record*) for each active function (cf. Java method) that has not yet returned
- It holds:
  - Room for local variables and parameters
  - The *return address* (index into code for what to execute after the function is done)
  - Other per-call data needed by the underlying implementation

What could go wrong?

- The programmer has to keep the bits straight even though C deals in terms of variables, functions, data structures, etc. (not bits)
  - If arr is an array of 10 elements, arr[30] accesses some other thing
  - Storing 8675309 where a return address should be makes a function return start executing stuff that may not be code
  - . . .
- Correct C programs can't do these things, but nobody is perfect
- On the plus side, there is no "unnecessary overhead" like keeping array lengths around and checking them!
- Okay, time to see C . . .

Hello, World!

- Code:
```
#include<stdio.h>
int main(int argc, char**argv) {
   printf("Hello, World!\n");
   return 0;
}
```
  - Compiling: gcc -o hi hello.c (normally add -Wall -g)
  - Running: ./hi
- Intuitively: main gets called with the command-line args and the program exits when it returns
- But there is a *lot* going on in terms of what the language constructs mean, what the compiler does, and what happens when the program runs
- We will focus mostly on the language

Quick explanation

```
#include<stdio.h>
int main(int argc, char**argv) {
   printf("Hello, World!\n");
   return 0;
}
```

- #include finds the file stdio.h (from where?) and includes its entire contents (stdio.h describes printf, stdout, and more)
- A function definition is much like a Java method (return type, name, arguments with types, braces, body); it is not part of a class and there are no built-in objects or “this”
- An **int** is like in Java, but its size depends on the compiler (it is 32 bits on most mainstream Linux machines, even x86-64 ones)
- **main** is a special function name; every full program has one
- **char**** is a long story…

Pointers

- Think address, i.e., an index into the address-space array
- If **argv** is a pointer, then ***argv** returns the pointed-to value
- So does argv[0]
- And if argv points to an array of 2 values, then argv[1] returns the second one (and so does *(argv+1) but the + here is funny)
- People like to say “arrays and pointers are the same thing in C”. This is *sloppy talking*, but people say it anyway.
- Type syntax: t* describes either
  - NULL (seg-fault if you dereference it)
  - A pointer holding the address of some number of values of type t
- How many? You have to know somehow; no length primitive

Pointers, continued

- So reading right to left: argv (of type char**) holds a pointer to (one or more) pointer(s) to (one or more) char(s)
- **Fact #1** about main: argv holds a pointer to j pointers to (one or more) char(s) where argc holds j
- **Common idiom**: array lengths as other arguments
- **Fact #2** about main: For 0 ≤ i ≤ j where argc holds j, argv[i] is an array of char(s) with last element equal to the character ’\0’ (which is not ’0’)
- **Very common idiom**: pointers to char arrays ending with ’\0’ are called *strings*. The standard library and language often use this idiom
- [Let’s draw a picture of “memory” when hi runs.]

Rest of the story

```
#include<stdio.h>
int main(int argc, char**argv) {
   printf("Hello, World!\n");
   return 0;
}
```

- printf is a function taking a string (a char*) (and often additional arguments, which are formatted according to codes in the string)
- "Hello, World!\n" evaluates to a pointer to a global, immutable array of 15 characters (including the trailing '\0'; and '\n' is one character)
- printf writes its output to stdout, which is a global variable of type FILE* defined in stdio.h
  - How this gets hooked up to the screen (or somewhere else) is the library's (nontrivial) problem

But wait, there’s more!

- Many variations that we will explore as time permits, starting with the next homework
  - Accessing program command-line arguments (argc and argv)
  - Other I/O functions (fprintf, fputs, fgets, fopen, …)
  - Program exit values (caller can check, e.g. in shell scripts)
  - Strings – much ado about strings
    - Strings as arrays of characters (local and allocated on the heap)
    - Updating strings, buffer overflow, ’\0’
    - String library (<string.h>)