CSE 374
Programming Concepts & Tools

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

To Do – Virtual Machine Fixes

- We're about to start C programming! Fantastic!!!
- But – there's an unfortunate bug in the CSE VM. If you're using that you need to update/replace one of the libraries.
- In your CSE Linux VM, run this is a terminal window:

  sudo dnf -y install glibc-devel.x86_64

- We will demo this later (and see what happens when not done – you get a message something like "fatal error: gnu/stubs-64.h: No such file or directory")
- This is fixed on klaatu so don't do it there

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, ...)

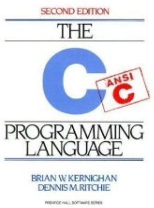
• A different world-view and much more to keep track of; Java-like thinking can get you in trouble

Our plan

A semi-nontraditional way to learn C:

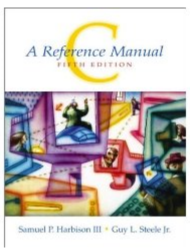
- Learn how C programs run on typical x86-64 machines
  - Not (totally) promised by C's definition
  - You do *not* need to "reason in terms of the implementation" when you follow the rules
  - But it does help to know this model
    - To remember why C has the rules it does
    - To debug incorrect 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



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



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

- Detailed reference on C and libraries; includes more recent versions of the C standard (but not C11)

Essential C, Stanford CS lib, http://cslibrary.stanford.edu/101/EssentialC.pdf
Good short introduction to the language

cplusplus.com (reference site linked from 374 home page)

- Good current reference for standard library

Why C?

- Small language (not very many features) – relatively easy to understand and implement efficiently
- Provides low-level control over the computer when needed, closer to assembly (machine) language
  – But still possible to write reasonably portable code
- Still used in:
  – Embedded programming
  – Systems programming
  – High-performance code
- And for CSE 374: learning to program in C will give you better insight into how computers work and how software interacts with the machine

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^{64} or 2^{32}
  - For most of what we do it doesn't matter
  - 2^{64} or 2^{32} is way more memory than you have, but OS maintains illusion that all processes have this much even if they don't
  - "Subscripting" this array takes 64 (or 32) 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 hello hello.c
    - (normally add -Wall -g -std=c11)
  - Running: ./hello
- 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 contiguous values of type T
- How many? You have to know somehow; no length primitive

```
int main(int argc, char**argv)
```

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 $0 \leq i \leq j$ 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 rely on this idiom
- [Let’s draw a picture of “memory” when hello 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
- Return value from main is program's exit code (caller can check, e.g., shell's $?)

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
  - 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>)
  - And more (structs, dynamic memory, …)

Advice

- Start reading K&R (*C Programming Language*) or your other favorite C book to get a view of how things are intended to work
- Use web/books to look up facts (“what’s the C function to compute compare strings”, “how do I format an integer for output in printf”)
  - C/C++ reference link on 374 web is a good start
- Try stuff – write little programs, experiment
  - Need to write/run code as well as read about it