CSE 374
Programming Concepts & Tools

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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

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:
  ```c
  #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

```c
#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 $0 \leq i \leq j$ 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 often use this idiom
- [Let’s draw a picture of “memory” when hi runs.]
Rest of the story

```c
#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>)