CSE 303:
Concepts and Tools for Software Development

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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 actually run on machines like `attu`
  - *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
- Later: A *little* C++

Some References

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

- *C: A Reference Manual*, Harbison & Steele (currently 5th ed.). Probably the best current reference on C and its libraries, updated with 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 extensions), but the primary source.
- *Essential C*, Stanford CS lib, `http://cslibrary.stanford.edu/101/EssentialC.pdf`. Good short introduction to the language by some friends at Stanford.

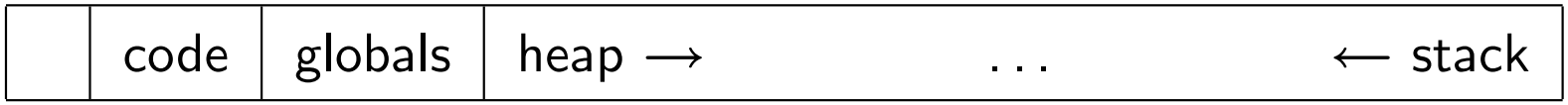
Address space

Simple model of a running *process* (provided by the O/S):

- There is one *address space* (an array of bytes)
  - Most common size today for a machine like `attu` is $\mathbf{2^{32}}$
  - We will "assume 32" for now, though you often shouldn't
  - That is more RAM than you (probably) have (O/S maintains illusion; may lead to slowness)
  - "Subscripting" this array takes 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.

Address-space layout

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



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 "seg-fault"
- A *call-stack* holding *local variables* and *code addresses*

Note: *Assuming* an `int` occupies 4 bytes

The stack

The call-stack (or just stack) has one "part" or "frame" (compiler folks call it an *activation record*) for each function (cf. Java method) call that has not yet returned.

It holds:

- Room for local variables
- The *return address* (index into code for what to execute after the function is done)

What could go wrong?

Remember, 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.
- Writing 8675309 where a return address should be makes a function 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!

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

- Compiling: `gcc -o hi hello.c` (usually 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 Hello Explanation

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

- `#include` finds the file `stdio.h` (from where?) and includes its entire contents. (`stdio.h` describes `fputs` and `stdout`.)
- 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, though its size depends on the compiler (it is 32 bits on `attu`).
- `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

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

- `fputs` is a function taking a *string* (a `char*`) and a `FILE*` (where `FILE` is a type defined in `stdio.h`).
- `"Hello, World!\n"` evaluates to a pointer to a global, immutable array of 15 characters (including a trailing `'\0'`, `\n` is *one* character).
- `stdout` is a global variables of type `FILE*` defined in `stdio.h`. How this gets hooked up to the screen (or somewhere else) is the library's (nontrivial) problem.

Variations of Hello World

Things we can try to *understand*, time permitting:

- print command-line arguments
- use `printf`
- change exit values
- use local variables to hold strings
- update string elements (won't work for constant strings)
- update string elements (including buffer overflow and overwriting the `'\0'` and putting a `'\0'` "early".