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CSE 374

# Programming Concepts & Tools

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

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# Welcome to C

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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

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A semi-nontraditional way to learn C:

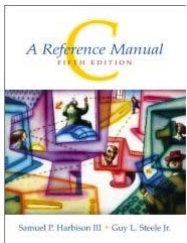
- Learn how C programs run on typical 32-bit x86 machines
  - Not promised by C's definition
  - You do *not* need to “reason in terms of the implementation” when you follow the rules
  - But it does help to know this model
    - To remember why C has the rules it does
    - To debug incorrect programs
- 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

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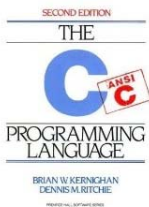
There's a lot on the web, but here are some primary sources.

*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 extensions), but the primary source.

Essential C, Stanford CS lib,

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

Good short introduction to the language

# Address space

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

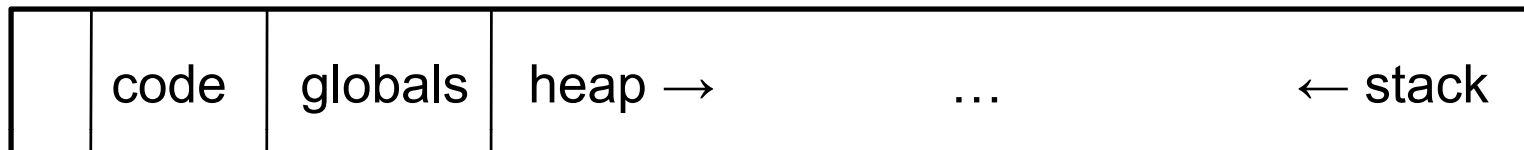
- There is one address space (an array of bytes)
  - Most common size today for a typical machine is  $2^{32}$ \*
  - We will “assume 32” for now, though you often shouldn’t
  - That is more RAM than you (probably) have\* (O/S maintains the  $2^{32}$  illusion even if you don’t; may lead to slowness)
  - “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

\*marks “fact” that is likely to become obsolete fairly soon

# Address-space layout

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- 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

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- 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?

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- 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 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!

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- Code:

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

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```
#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, though its size depends on the compiler (it is 32 bits on most mainstream Linux machines).
- `main` is a special function name; every full program has one.
- `char**` is a long story...

# Pointers

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- 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

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- 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

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```
#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!

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- Many variations that we will explore as time permits
  - Accessing program command-line arguments (argc and argv) – part of next homework
  - 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