C

The Short, Short Version

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Why C?

• Powerful, efficient access to hardware
  – Pointers!
• Crazy fast, no interpreter nonsense
• Compiles on almost every piece of hardware ever
  – Core “ANSI C” is portable
  – If you use OS calls, you probably aren’t portable, but that’s justified
    • C is close to the hardware and OS, so code must differ between architectures – no abstraction to help/hinder you
Smallest program

```c
int main(){}
```

- Not very good:
  - Doesn’t do anything
  - Doesn’t specify what is returned

Smallest program with output

```c
#include <stdlib.h>
#include <stdio.h>

int main() {
    printf("Hello World!\n");
    return EXIT_SUCCESS;
}
```

- Better:
  - Outputs to stdout using printf, defined in stdio.h
  - Returns EXIT_SUCCESS, defined in stdlib.h
Syntax (1)

- Whitespace is irrelevant
- Comments:
  /* Anything, including newlines */
  // Anything to end of line
  • Really a C++ comment, but ok in modern C
- Literals:
  - Numbers: 5, 25, 0xFF, 0777
  - Characters: 'c', 'b', '\n', '\0'
  - Strings: “This is an example”, “So is this”
  • More on this later...
- Include directives:
  #include <somefile.h> // System file
  #include "myfile.h" // Our file

Syntax (2)

- Data types:
  - char, int, long, float, double
  - Size of int? long? It depends. Use sizeof(<TYPE>) to get byte size of a data type. Both int and long are 32-bit=4-byte for us.
  - Can put “unsigned” in front of an integer type:
    int x=0xFFFFFFFF; // This is -1
    unsigned int y=0xFFFFFFFF; // 2^32-1 = 4294967295
Syntax (3)

- Functions:
  ```
  float magnitude(float x, float y) {
    return sqrt(x*x + y*y);
  }
  void printHello() { printf("Hello\n") }
  ```

- Global variables, outside of functions:
  ```
  int v=1;
  const float PI = 3.14159;
  int main() {v=5;}
  ```

- Local variables, inside of functions:
  ```
  int main() {int v=5;}
  ```

- Data type conversions (casts):
  ```
  int a=5; float f = (float)a; // f=5.000
  float g=5.9; int b = (int)g; // b=5
  ```

Syntax (4)

- Operators:
  - Arithmetic: + - * / % (mod)
  - Binary: ^ (xor) & (and) | (or) ~ (compliment)
    - Bit shifting: << >>
  - Logical: && (and) || (or) ~ (not)
  - Assignment: =
  - Comparisons: != == < <= >= >
  - Choice: b?x:y
    - If b is true, then evaluate to x, else evaluate to y
  - Modifying:
    - x++ (increment after eval), ++x (increment before eval)
    - Slap a = after any operation ✳ to modify the LHS:
      - x ✳ y; SAME AS x = x ✳ y;
Syntax (5)

- **Control (assume int i):**
  - **Conditional:**
    ```c
    if (i>=0 || i<5) { printf("i=%d in range\n",i); }
    ```
  - **Loops (each outputs “01234”):**
    ```c
    for (i=0; i<5; i++) { printf("%d",i); }
    ```
    ```c
    while (i<5){ printf("%d",i); i++; }
    ```
  - **Multicase conditional:**
    ```c
    switch (i) {
    case 1:
    case 2:
      printf("i is 1 or 2\n");
      break;
    default:
      printf("i is neither 1 nor 2\n");
    }
    ```

Pointers (1)

- **Pointers are simply **memory addresses**!**
- **Declaring a pointer:**
  ```c
  int* ptr; // ptr refers to a int (4 bytes for us)
  ptr = NULL; // Set to NULL (zero)
  ```
  - Setting new pointers to NULL makes uninitialized pointers more obvious in the debugger, you can test them for falsehood in conditionals
- **Using a pointer:**
  ```c
  ptr = 5; // Now points to memory address 0x5
  ```
  - You never want to do this...always want to set to the address of something
  ```c
  int x; ptr = &x; // Now points to address occupied by x
  ```
  - & means “Address of”
  ```c
  ptr++; // Now points to address 4 bytes later (undefined!)
  ```
  - Math on pointers occurs not at the byte level, but at the data type level!
Pointers (2)

- Accessing a pointer’s reference:
  ```c
  int x; int* ptr = &x;
  (*ptr) = 5; // Same as x=5!! wow!!
  - * is also the “Dereferencing operator” when
    prepended to pointers
    - Don’t bother trying to guess order of operations with
      this, too dangerous.
    - Just use parentheses on them all the time.
  - Can have multiple levels of indirection:
    ```c
    int x;
    int* p = &x;
    int** pp = &p;
    (**pp)=5;
    ```

Arrays

- An array is just a pointer to a block of memory! Wow!!! Two kinds of arrays:
  - On the stack, either as a global or in a
    function as a local variable
    ```c
    float coords[3] = {1.0,2.0,3.0}; // Initialize
    int main() { int x[64]; x[0]=5; }
    - You must know the size at compile time
    - Memory is reclaimed automatically by the operation
      of the stack
  - On the heap...
Heap Memory Allocation

- Create a pointer:
  ```
  int* values;
  ```
- Use a memory allocation call to reserve a block of heap memory of any size (even a runtime variable `n`):
  ```
  values = (int*)malloc(n*sizeof(int));
  values = (int*)calloc(n,sizeof(int));
  ```
- If you want all the elements to be initialized, you have to do it yourself
  ```
  for (i=0; i<n; i++) values[i]=0;
  ```
  (calloc might init block with zeroes, but don't count on it)
- You can resize dynamically:
  ```
  num *= 2; values = (int*)realloc(values,num);
  ```
- **YOU must free memory yourself!**
  ```
  free(values);
  ```

Strings

- What is a string?
  - Just an array of type `char`! WOW!
    ```
    char strOnStack[64] = "This can’t be more than 64 chars ever!"
    char* strOnHeap; strOnHeap=malloc(64);
    strcpy(strOnHeap,"Neither can this!");
    ```
    - Why not `strOnHeap = "Some stuff"`?
  - But the array is one size (64) and the string is another...how do we tell when the string ends?
    - Null terminator: add a zero character to the end (written as '\0' usually)
      - Done automatically by any string functions, but if you roll your own string, don't forget it...
Using Pointers as Arguments

- Normal function:
  ```c
  void f(int x) {} // Normal function
  • the value of x is given ("pass by value")
  ```
- How about:
  ```c
  void f(int* x) { (*x)=5; }
  ```
- Now the function gets a pointer instead of the value ("pass by reference")
  - The function can CHANGE the variable referred to:
    ```c
    int a=2; f(&a); printf("a=%d\n",a);
    - Outputs "5"
    ```
- Parameters can now be thought of as input, output, or both

What does main() accept?

- We’ve shown the simple main:
  ```c
  int main() {}
  ```
- To accept command line arguments, you’ll need:
  ```c
  int main(int argc, char** argv) {}
  • You are given the number of arguments argc, and an array of strings argv
  • argv[0] is always the name of your binary
  • argv[1] is the first argument, argv[n] is the nth argument
  • If argc==2, then argv has indices 0,1.
Structures (1)

- Can rename data types with typedef:
  ```
  typedef char bool; // Make a bool type
  ```
- Can blob together data types to form a larger type:
  ```
  struct Thing {
    int value;
    char buffer[64];
  };
  ```
- Access (given Thing t, Thing* tp=&t):
  ```
  t.value = 5;
  (*tp).value = 5;
  tp->value = 5;
  ```

Structures (2)

- Declaring variables based on this is a bit ugly:
  - It's: struct Thing t;
  - NOT just: Thing t;
- Solution: combine struct with typedef:
  ```
  typedef struct {
    int value;
    char buf[64];
  } Thing;
  ```
- Can have pointers to these: Thing* obj;
  - This is what objects are in OO languages!
- Custom data types often written as something_t
IO (1)

- Terminal output:
  - `printf(char* format, [varlist]);`
  - Example:
    ```c
    int i=32; float x=2.5; char c='x';
    char buf[64] = "Banana";
    printf("i=%d 0x%x  x=%f  c=%c buf='%s'\n",i,i,x,c,buf);
    ```
  - Output:
    ```
    i=32=0x20  x=2.5  c=X  buf='Banana'
    ```
- Terminal input:
  - `scanf(char* format, [varlist]);`
  - You pass POINTERS in varlist to things you want overwritten: `int x; scanf("%d", &x);`
  - Check the man page for details!

IO (2)

- File IO
  - `FILE* fp;`
  - `fopen(char* file, char* mode);`
    - mode is `<r|w|a>|[b][+]
  - `fprintf(FILE* fp, char* fmt, [varlist]);`
  - `fscanf(FILE* fp, char* fmt, [varlist]);`
  - `feof(FILE* fp);` // True if EOF
  - `fwrite/fread(void* buf, size_t size, size_t count, FILE* fp);` // Binary read and write are symmetric!
  - `fclose(FILE* fp);`
- Check a stdio.h reference for a full list!
IO (3)

- Example: Sum all ASCII ints from in.dat and save as binary int in sum.dat
  ```c
  int x,sum;
  FILE* fp; // File handle, internals irrelevant
  fp = fopen("filename.dat","r"); // Open for read
  if (!fp) { printf("error!\n"); exit(1); } // Error
  // Read and sum all ASCII expressed ints
  while (fscanf(fp,"%d",&x) == 1) {
    sum += x;
  }
  fclose(fp); // Close file
  fp = fopen("sum.dat","wb"); // Open binary write
  fwrite(&sum,sizeof(int),1,fp); // Write binary int
  fclose(fp); // Close file
  ```

IO Remarks

- **MIND YOUR BUFFER SIZE!!!!**
- Why?
  - File in.dat has “abcdefg”, opened as FILE* fp
  - Read word with:
    ```c
    char buf[5];
    fscanf(fp,"%s",buf);
    ```
  - OH MISERABLE DAY! You have just written data into memory you don’t own. Prepare to crash.
  - Solution:
    - fscanf(fp,"%4s",buf);
      - Why 4 instead of 5? ‘\0’
    - Same goes for fread, fwrite, etc. Read the docs!
The Preprocessor

- The preprocessor does text-level actions to your code based on directives starting with `#`:
  - `#include <stdio.h>`
    - Put all of stdio.h right here
  - `#define PI 3.14159`
    - Replace the token PI with 3.14159 in code
  - `#if DEBUG`
    - `<SOMECODE>`
    - `#endif`
    - Take out `<SOMECODE>` unless DEBUG has been defined as a nonzero value

Multi-file Projects

- Two modifiers to apply to globals and functions:
  - `extern`: Don’t define it here, just declare it and note that it is in an `external` file.
  - `static`: Force it to stay in this file, nobody else can get at it (even with extern)
Multi-file Example

- File myCode1.c:
  ```c
  int a;
  const double pi = 3.1415;
  static int sum(int n, int m) {
      return (n+m);
  }
  ```
- File myCode2.c:
  ```c
  int b;
  extern const double pi;
  static double sum(double n, double m) {
      return(n+m);
  }
  ```

Multi-file Example Comments

- The integers a and b have external linkage and may be seen in both files (if they are both part of the same program).
- The value of pi is defined to be external in myCode2. It will be the same memory location as pi is in myCode1.
- Both declarations of sum are valid, but the are limited in scope to their respective file.
Header files (*.h)

- Need a better way than manual declarations
  - You’d have to declare every function you wanted to use out of stdio, for example.
- Solution: Header files!
  - `#include <stdio.h>` means “put all of stdio.h here”
  - stdio.h contains declarations of functions defined elsewhere and compiled into libraries

Headers Have the 3 D’s

- **Declarations** of externally linked functions
- **Documentation** for those functions!
- **#Defines** of various flags and constants
  - Ex: Put a `#define DEBUG 1` in a common header, then surround all debug output code with `#if DEBUG` and `#endif`. You can choose to include or discard this code during compilation by changing one flag!
- *Nothing else! No code!*
Avoiding Header Collisions

- Two source files include the same custom header file that declares int x, and you compile both at the same time
  - You’ve just declared int x twice! Oh no!
- Use the preprocessor to make headers behave well. Example myfile.h:
  ```
  #include <stdio.h>
  #ifndef MYFILE_H
  #define MYFILE_H
  <<HEADER STUFF>>
  #endif
  ```

Compiling

- A single source file S1.c to a binary:
  ```
  gcc -o MyBinary S1.c
  ```
- Add symbolic debug support to binary:
  ```
  gcc -g -o MyBinary S1.c
  ```
- Compile two source files:
  ```
  gcc -g -o MyBinary S1.c S2.c
  ```
- Include some library called potato:
  ```
  gcc -g -lpotato -o MyBinary S1.c S2.c
  ```
Compiling (2)

- But why recompile *every* file *every* time, even if you just change one?
- Compile to *object files*:
  ```
gcc -g -c S1.c
  ```
  - Produces S1.o
- Combine all these .o files into a binary
  ```
gcc -o MyBinary S1.o S2.o ...
  ```

Makefiles

- Guess what has been changed and manually type all those commands?
  - I’m too lazy for that nonsense.
- Makefiles!
  - Create a graph of dependencies
    * "if Y is built on X and X is new, then turn the new X into a new Y"
  - Format:
    ```
    <VARNAME> = <VALUE>
    <THING>: [DEPENDENCY] [DEPENDENCY] ...
    »TAB» <COMMANDS TO MAKE DEPENCIES INTO THING>
    ```
  - Syntax:
    ```make [ Thing to make, defaults to first in Makefile]```
Prototype Makefile

```makefile
# Comment out on Linux
LIBS = -lsocket -lns1
OBJJS = $1.o $2.o

all : MyBinary

.c.o:
gcc -g -c $<

MyBinary : $(OBJJS)
gcc $(LIBS) -o $0 $(OBJJS)

clean:
rm $(OBJJS) MyBinary
```

Debugging: the problem

- A bad program called lousy.c:
  ```c
  int main() {
      int& ptr;
      (*ptr) = 5; // Where does this 5 go?
  }
  ```
- Compiles ok (C will never judge you!)
  $ gcc -g -o lousy lousy.c
- Run:
  $ ./lousy
  Segmentation fault

Super happy fun message!
Debugging: gdb to the rescue

$ gdb lousy
<<WELCOME MESSAGE>>
(gdb) run
<<SOME INFO>>
Program received signal SIGSEGV, Segmentation fault.
0x08048367 in main () at x.c:3
3  (*ptr)=5;
(gdb) list
1  int main() {
2     int* ptr;
3     (*ptr)=5;
4 }
(gdb) bt
#0 0x08048367 in main () at x.c:5
(gdb) print ptr
$1 = (int *) 0x8048370

Standard libraries (1)

- stdio.h
  - You’ve seen most of this: printf, fopen, etc.
- stdlib.h
  - A lot of very fundamental things, like memory allocation, string/number conversions, environment manipulation, and process execution
Standard libraries (2)

- string.h
  - String copying, concatenating, length, etc.
- time.h
  - Get current time, manipulate time values
- math.h
  - abs, cos, exp, log, pow, sin, tan, etc.

What about C++?

- All C programs are C++ programs, as C++ is an extension to C
- C++ loosens some restrictions, adds some syntactic niceness (such as declaring variables in the initialization of a for loop), and most importantly formalizes OO as part of the language.
- We aren’t doing C++, but some of the niceness has been carried back to C (my favorite being the // single line comments)
Warning:
You now know just enough C to be dangerous!

- I haven’t covered all of the language, only what you need to get going right now
- To learn more, you can:
  - Check out the CSC253 notes at http://courses.ncsu.edu/csc253/lec/001/, which I shamelessly stole from, since that’s where I learned most of this
  - Read about standard library calls at http://www.cplusplus.com/ref/
  - Get any good introductory C book
    - I recommend books published by O’Reilly
  - Read any number of C tutorials on the web

Any questions?