Linux kernel and C programming

BLOCK 1: Introduction to the C language

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February 18, 2025

Presentation Overview

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Introduction

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Requirements

The course will cover basic programming knowledge of the C language, and how to create Linux kernel modules and user applications.

Requirements:

- Attendance
- 50p One midterm exam
- 50p One assignment (choose until 4th class)

The midterm exam and the assignment will worth 50 points each. The total of 100 points will result in the closing mark.

Semester

1. Introduction to C (hello world, GCC, CMake)
2. Memory basics (cache, stack, heap, page(s))
3. CMake (variables, if/else)
4. Function pointers, unions and argc/args
5. Typedef, extern, static and compiler optimization
6. Introduction to Linux kernel modules (kmake, files)
7. Kernel proc files
8. Kernel dev files
9. C compile process (preprocess, compile, link)
10. CMake linker flags
11. Midterm exam practice
12. Midterm exam
13. Midterm assignment presentations
14. Midterm exam and assignment presentations retake

Purpose

The purpose of this course it to get the technical knowledge of the C programming language.

This course is not for beginners, I expect you to have some prior programming experience. (like C#)

Introduction to C

History

The C programming language is very simple. Although using it can be quite difficult, due to memory management and other. But provides freedom.

C is a general-purpose programming language, and was created in the 1970s by *Ken Thompson* and *Dennis Ritchie*.

It was mainly developed to replace assembly, and create portable code/programs.

".. for the first two years their main tool was the assembler language. The labor intensity of writing machine code forced them to look for a replacement, which eventually became the C language. With its help, the operating system kernel and most of the utilities were completely rewritten. The C language allowed for the creation of effective low-level programs on the PDP-11, practically without using the assembler language."

After you programmed enough C

Types

C is a strongly typed programming language. To declare a variable you need to write the `type` before it. The size of a variable will depend on the architecture, but lets see the sizes for a 64 bit processor.

Type	Size	Description
`char`	`8 bit`	Signed Character (treated as int)
`short`	`16 bit`	Short Signed integer.
`int`	`32 bit`	Signed integer.
`long`	`64 bit`	Long Signed integer.
`float`	`32 bit`	Single precision floating point.
`double`	`64 bit`	Double precision floating point.

You can read out the bytesize of a variable by using `sizeof()`.
Use the standard int library `stdint.h` for types like `uint8_t`.

Variables

Variables are (?)not zeroed out at initialization. Therefore when we declare a variable, by default they will have the previous value of the memory they were assigned to.
To assign a variable we can use the **=**, **+=**, **-=**, ***=**, **/=** and **%=** operators

```
1 int a;
2 int b = 0;
3
4 int c = 2, d = 4;
```

We can do math between them, by using the **+**, **-**, ***** and **/** operators.

```
1 a = d - b;        // a: 4
2 int e = a * c     // e: 8
```

Type modifiers

Modifier	Description
`signed`	Ensure a variable is signed.
`unsigned`	Ensure a variable is unsigned.
`short`	Shortens the variable size by half. *(if possible)*
`long`	Doubles the variable size. *(if possible)*

```
1 unsigned int a = 4;
2 long long b = 3;
3
4 b += a;
```

Macros

Macros will only be used at preprocessing, and will be inserted into the code as is. They can contain function like variables, which will be used at preprocessing. Lets see a short example:

```
1  #define debug_string     "[debug]: "
2  #define mystring         "words in my head"
3  #define number1          75434
4  #define number2          1234
5  #define sum(a, b)        a + b
6  #define mul(a, b)        (a * b)
7
8  printf(debug_string "%s - %d\n",
9         mystring, sum(number1, number2));
10
11 // will be compiled as:
12 printf("[debug]: " "%s - %d\n",
13         "words in my head", 75434 + 1234));
14 // will print: [debug]: words in my head - 76668
```

Memory

You can look at computer memory as an array of bytes. It can be indexed from 0 to the sky.

When running your program you will get a slice of memory to use from the kernel. This is where your application will be loaded.

Pointers

Pointers are also variables, which point to an arbitrary memory location.

```
1 int a = 10;
2 int* p = &a;      /* will set the value of 'p' to the
3                      address of 'a' */
4 *p = 5;           /* will set the value at the address
5                      inside 'p' to 5, therefore 'a'
6                      will be 5 */
7 p = 10;           /* will set the value of 'p' to 10,
8                      the value of 'a' will stay 5 */
```

Pointer arithmetics

Modifier	Description
`&p`	Get the memory address of variable `'p'`.
`*p`	Get the value pointed by `'p'`.
`p++`	Multiply the value of `'p'` by the bytesize of its type.
`p--`	Subtract the value of `'p'` by the bytesize of its type.
`p + n`	Multiply the value of `'p'` by the bytesize of its type times `n`.
`p - n`	Subtract the value of `'p'` by the bytesize of its type times `n`.
`p[n]`	The same as `*(p + n)`.

Arrays

In C, arrays are pointers, with a predefined length of memory. They can be declared like the following:

```
1 int array[10];
2 int array[5] = { 0, 1, 2, 3, 4 };
3 int array[] = { 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 };
```

We can access the element of an array, by its index like:

```
1 array[0] = 2;
2 array[2] = 4;
3 int a = array[3];
```

Arrays

We can also user pointers as arrays:

```
1 int array[10];
2 int* p = array;
```

An array is just a pointer to an already allocated memory area. Therefore we can also get the n-th value like the following:

```
1 int array[] = { 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 };
2 int a = *(array + 3);    // a will be 3
```

Conditions

C don’t have booleans, therefore a condition is true if it is not 0, and false if it is.

```
1 if (0) {
2     // Will always be false
3 }
4 if (1) {
5     // Will always be true
6 }
7 if (-5) {
8     // Will always be true
9 }
```

Conditions

We can use the following conditional operators:

Operator	Description
!	Not
>	Greater than
<	Lesser than
==	Equals
!=	Not equals
&&	And
||	Or

Loops

We can talk about `while`, `do while` and `for` loops.
While and do while will run until the provided condition is not 0.

```c
int i = 5;

// Will print the numbers from 5 to 1
while (i) { // can also be (i > 0)
    printf("%d\n", i);
    i--;
}

// Will print the numbers from 0 to 4
while (i < 5) {
    printf("%d\n", i);
    i++;
}
```

Listing 1: While loop

Loops

For loops will run until the condition is 0. They contain an index (see `'i'`), which is incremented over each cycle.
The condition can also contain pointers, and in some cases you can see it being used like a foreach.

```
1  int i = 0;
2
3  // Will print the numbers from 0 to 4
4  for (i = 0; i < 5; i++) {
5      printf("%d\n", i);
6  }
7
8  // Will print the numbers from 1 to 5
9  int array[] = { 1, 2, 3, 4, 5, 0 /* NULL */};
10 int* my_pointer = &array[0]; // an array closed by 0
11 for (; NULL != *my_pointer; my_pointer++) {
12     printf("%d\n", *my_pointer);
13 }
```

Bitwise operations

Bitwise operations execute the following on ether one or two different variables:

Operator	Description
&	And
|	Or
<<	Shift Left (x2)
>>	Shift Right (/2)
~	Inverse
^	XOR

Structs

C structs are complex variables with named fields. The variables will be declared at the same memory location, after each other. They are often used in headers, like in TCP.

```
1  struct my_struct {
2      int a;
3      int b
4      float c;
5      bool d;
6  }
7
8  struct my_struct my_struct_var1 = { 0 };     // fill with 0
9  struct my_struct my_struct_var2 = {
10     .a = 5;
11     .c = 0.6f;
12 };
13
14 my_struct_var1.b = 12;
```

Functions

Functions start with the return type, followed by the name, and parameters.

```
1  /*
2   * <return type> function_name(<void/int a, ...>) {
3   *      // do stuff
4   * }
5   */
6
7  int main() {
8      printf("hello world!");
9      return 0;
10 }
```

Headers

Header files are like interfaces in other programming languages. Depending on the usage they contain defines, types definitions and function definitions.
We can include them with: `#include "header.h"`.

Headers

shouldn't contain function declarations!

You will also see `#include <stdio.h>`. The difference between referring to an include with `""` and `<>` is that brackets are used for the standard library and system headers, while double quotes refers to user defined "local" headers.

Headers example

```c
// my_header.h
struct my_struct {
    int a;
}

int my_func(void);
```

```c
// my_program.c
struct my_struct struct_var = { 0 };

int my_func() {
    return 13;
}
```

Headers example

```c
// main.c
#include <stdio.h>
#include "my_header.h"

int main() {
    struct_var.a = my_func();
    printf("My a: %d", struct_var.a);
    return 0;
}
```

Strings

Strings are an array of characters. They can ether be stored in an ”array”, or a pointer.
They are always terminated by a trailing `0` character, which can be written with
`0`.

```
1 char* my_string = "Hello World!";
2
3 printf("My message: %s\n", my_string);
```

Printf

`printf()` is part of the standard library. It requires a format string, and extra arguments if they are defined in the format string.
The syntax is:

```
1 #include <stdio.h>
2 printf("format_string", args...);
```

The format string can contain format specifiers:

Specifier	Description
%d	Signed integer
%u	Unsigned integer
%c	Character
%f	Floating-point number
%x	Hex number format
%s	String closed by a zero character \0
%%	Print the % character

Printf

The format specifier can also be extended for prefilling by writing the character and the length of characters printed. For example:

```
1 printf("My Hex: 0x%08x\n", 0xAB13);
2 // will print: My Hex: 0x0000ab13
3
4 printf("My Hex: 0x%08X\n", 0xAB13);
5 // will print: My Hex: 0x0000AB13
```

The precision of floating-point numbers can also be specified as:

```
1 printf("My float: %.2f\n",      2.3456);
2 // will print: My float: 2.34
3 printf("My float: %02.1f\n",    2.3456);
4 // will print: My float: 02.3
```

Compiling

GCC

The GNU Compiler Collection includes front ends for C, C++ and others. It was developed for the GNU operating system, but still widely used and 100% open source.

Example

A simple way to compile our program is to provide our `.c` files as arguments.

```
1 gcc my_program.c
```

We can set the name of the output binary with `-o`

```
1 gcc my_program.c -o my_program
```

GCC

GCC will look for the includes file in the folder it is being run from. If you wish to provide extra folders for include files, you can use the `-I` flag.

Example

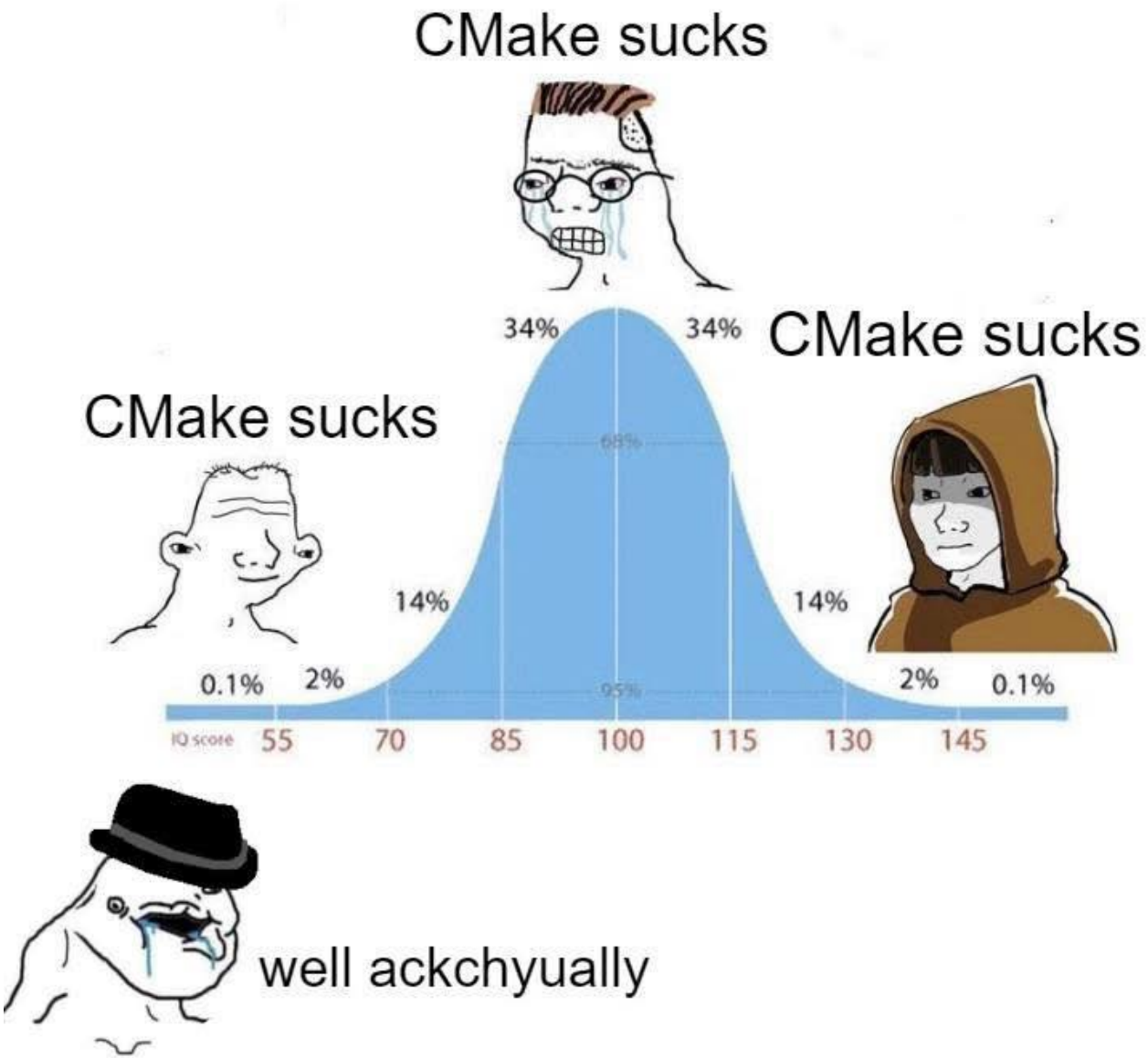
```
1 gcc my_program.c -Iinclude-dir
```

You can provide extra defines by usint the `-D` flag.

Example

```
1 gcc my_program.c -Iinclude-dir \
2     -DMYDEFINE1 -DMYDEFINE2=1
```

CMake


CMake sucks
34%
34%
CMake sucks
CMake sucks
14%
14%
0.1%
2%
2%
0.1%
IQ score
55
70
85
100
115
130
145
well ackchyually

CMake

CMake is a tool (extending Make) to help building larger projects in C and C++.

It uses the `CMakeLists.txt` files to specify the compile options.

Basics

Command	Description
`project()`	Specify the project name, and language
`include_directories()`	Add include directories
`add_executable()`	Add source files
`set()`	Set CMake variable

CMake Example

Example `CMakeLists.txt` for compileing `hello_world.c`:

```
1  cmake_minimum_required(VERSION 3.22)
2  set(CMAKE_C_COMPILER gcc)
3
4  project(hello C)
5
6  set(CMAKE_RUNTIME_OUTPUT_DIRECTORY
7      ${CMAKE_BINARY_DIR}/bin)
8
9  include_directories(${CMAKE_CURRENT_SOURCE_DIR}/include)
10
11 add_executable(hello hello_world.c)
```

CMake Build

You can build a CMake project with:

```
cmake -S . -B __build
cmake --build __build
```

The `-S` flag specifies the `source`, and the `-B` flag specifies the `build` directory.

Hello World

Lets write our first application. Create a `hello_world.c` file, and write the following:

```
1 #include <stdio.h>
2
3 int main() {
4     printf("Hello World!\n");
5     return 0;
6 }
```

Lets compile our program with:

```
1 gcc hello_world.c -o hello
```

Lets run our program with:

```
1 ./hello
```

Exercises

The End

Questions? Comments?