Parallel Computing with GPUs

An Introduction to C
Part 1 - Hello World

The University Of Sheffield.

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http://paulrichmond.shef.ac.uk/teaching/COM4521/

This Lecture (learning objectives)

- Introduce the C programming language
  - Identify the context of the language
  - Classify compiled vs interpreted
- Basic C usage: "Hello World"
  - Recognise the basic structure of a C program
  - Categorise the different parts of the compilation process
  - Distinguish appropriate use of casting
  - Recall appropriate use of `const`

About C

- Developed in the 70s
- Low Level
  - Compiled language
  - Close to machine code (more expressive than assembly)
- Procedural Language
  - Follows **in order** a set of commands
- Weakly Typed Language
  - Some basic C data types (but no data types in assembly)
  - Unchecked casting
  - No objects, sets or strings
- Simple fundamental control flow
  - `if, else, else if`
  - `switch`
  - `do, while, for, break, continue`
  - We will ignore `GOTO`:

C Standardisation

- C89/ANSI C:
  - Based on famous reference manual "K&R C"
  - Proposed by American National Standards Institute
- C90:
  - ISO standard 9899:1990
  - Technically the same as C89
- C99:
  - Addition of inline, Boolean, floating point
  - Most common C standard implemented by compilers
  - '*strict*' – implies the compiler follows the standard exactly
- C11:
  - Addition of multi threading support and atomics

Compiled vs Interpreted

- (C *is a*) Compiled Language
  - Compiler translates language into native machine instructions
  - Machine instructions do not port between architectures
  - Can be very powerful and high performance
- (C *is NOT an*)Interpreted Language
  - Read by an interpreter which executes the program
  - JAVA, Python etc.
  - Generally much slower (more overhead)
  - Just-in-Time (JIT): compilation at runtime to balance performance and portability

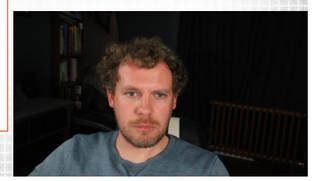
Hello World

- Control flow has influenced many other languages (e.g. JAVA)
- `#include` directive: parsed by pre processor
- `printf`: basic output
- `main`: standard entry point
- Comments (`//` single line or `/* */` multiline)
- `return`: Main can return 0 to indicate success or anything else to indicate an error code

```c
/* Hello World program */

#include <stdio.h>

int main()
{
    //output some text
    printf("Hello World");
    return 0;
}
```

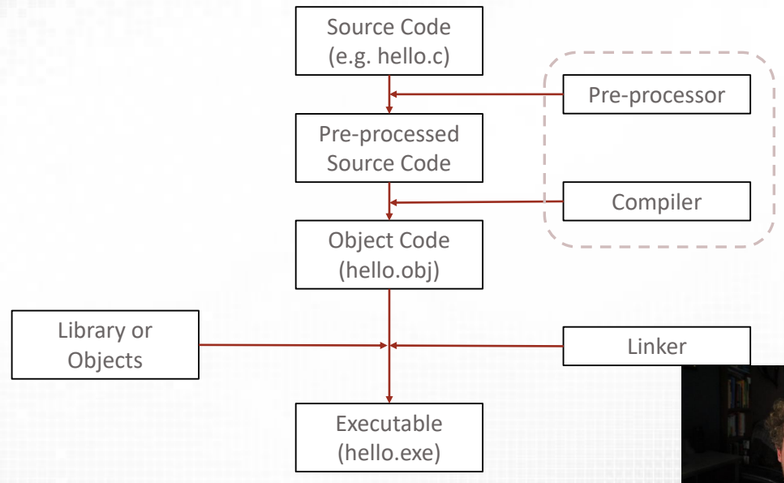


Directives and Pre-processor

- `#include`: includes the contents of a file
  - `#include <file>`: system header files
  - `#include "file.h"`: user header files relative to working directory
- Macros
  - `#define SOME_VALUE 1024`
    - Pre-processor performs substitution in expressions.
    - E.g. `int x = SOME_VALUE;`
  - Function-like macros
    - Can have arguments
    - E.g. `#define add_one(x) (x+1)`
    - Used as: `int x = add_one(SOME_VALUE);`
  - `#if, #elseif, #else, #endif`:
    - Used to perform directive conditionals
  - `#ifdef, #ifndef`
    - If defined and if not defined: Useful for platform specific code

```c
#ifdef WIN32
#include <windows_header.h>
#else
#include <linux_header.h>
#endif
```

Compilation



Data types

- All sizes are compiler and machine dependant
  - `char` a single byte or single character
  - `int` a 4 byte integer
  - `float` single precision floating point (4 byte)
  - `double` double precision floating point (8 byte)
- Integer qualifiers (can omit `int`)
  - `short` `short` is 2 bytes
  - `long` `long` = `int` BUT `long long` is an 8 byte integer
- Integer and char qualifiers (affects range)
  - `signed` positive and negative
  - `unsigned` positive only
- `sizeof()` function returns size of variable or type
  - E.g. `int a; sizeof(a) = 4;`
  - `sizeof(int) = 4;`

Implicit Casting

- Implicit casting
  - When **operands** have different types the compiler will implicitly convert them
    - Also occurs in function arguments and return values
  - Implicit casting follows a promotion hierarchy (using rank)
    - `char < short < int < long < long long < float < double < long double`
    - Implicit casts always move variables up the rank
    - Order of evaluation is important!

```
int  i = 17;
char c = 'c'; // ascii value is 99
int sum;

sum = i + c;
```

Explicit Casting

- Explicit Casting
  - Cast operator `(type)` can be used on expressions or variables
  - Be careful
    - Integer truncation: `(int) 9.999999f == 9`
    - You might loose precision: `(char) 256 == 0`

```
int i, j;
double result;
i = 1;
j = 3;
result = i / j;
```

What is result?

Explicit Casting

- Explicit Casting
  - Cast operator `(type)` can be used on expressions or variables
  - Be careful
    - Integer truncation: `(int) 9.999999f == 9`
    - You might loose precision: `(char) 256 == 0`

```
int i, j;
double result;
i = 1;
j = 3;
result = i / j;
```

What is result? 0

```
int i, j;
double result;
i = 1;
j = 3;
result = (double) i / j;
```

What is result?

Explicit Casting

- Explicit Casting
  - Cast operator `(type)` can be used on expressions or variables
  - Be careful
    - Integer truncation: `(int) 9.999999f == 9`
    - You might loose precision: `(char) 256 == 0`

```
int i, j;
double result;
i = 1;
j = 3;
result = i / j;
```

What is result? 0

```
int i, j;
double result;
i = 1;
j = 3;
result = (double) i / j;
```

What is result? 0.33333

const and volatile

- What does `const` mean? (e.g. `const int a = 10;`)
  - The variable is not unintentionally modifiable
    - Compiler error if you try to modify it
  - Not quite the same as read only
    - Something else might change it if it is volatile as well!
  - Can I cast a `const` to a non `const`
    - Yes, you can intentionally modify in this way but may lead to undefined behaviour
    - Implicit casting raises a compiler error
- What does `volatile` mean? (`e.g. volatile int a;`)
  - The value may change at any time regardless of code
  - Useful in embedded systems where value may be mapped to hardware
  - Prevents compiler performing optimisations on the variable
    - Which may be unsafe if the value changes

const and volatile

- What does `const` mean? (e.g. `const int a = 10;`)
- What does `volatile` mean? (`e.g. volatile int a;`)

Summary

- Introduce the C programming language
  - Identify the context of the language
  - Classify compiled vs interpreted
- Basic C usage: “Hello World”
  - Recognise the basic structure of a C program
  - Categorise the different parts of the compilation process
  - Distinguish appropriate use of casting
  - Recall appropriate use of `const`
- Next Lecture: Functions and scoping

Parallel Computing with GPUs

An Introduction to C Part 2 – Functions and Scoping

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This Lecture (learning objectives)

- Functions and scoping
  - Differentiate a declaration from a definition
  - Recognise the implications of variable scoping
  - Identify appropriate usage of the keywords `extern` and `static`

Functions

- Function definition

```
return-type function-name(optional-const argument-type argument-name, …)
{
    definitions;

    statements;

    return return-value or expression;
}
```

- Arguments are always passed by value
- No return type implies void (return can be omitted)

Declaration vs Defintion

- *A **declaration** introduces an identifier and describes its type, be it a type, or function. A **declaration** is what the compiler needs to accept references to (i.e. uses of) that identifier. E.g.*

```
extern int a;
int sum(int a, int b);
extern int sum(int a, int b);
```

- A ***definition*** actually instantiates/implements this identifier (and allocates memory for it). It's ***what the linker needs*** in order to link references to those entities. These are definitions corresponding to the above declarations:

```
int a;
int a = 1;
int sum(int a, int b){ return a + b; }
extern int sum(int a, int b) { return a + b; }
extern int a = 1;
```

More Examples: https://www.geeksforgeeks.org/understanding-extern-keyword-in-c/

Scoping

```c
#include <stdio.h>

int square(int a)
{
    return a*a;
}


int main()
{
    int result;
    result = square(a);

    printf("Square of 4 is %i", result);
    return 0;
}

int a = 4;
```

- Scoping lasts from where a variable or function is declared
- What is wrong with the following?

Scoping

```c
#include <stdio.h>

int square(int a)
{
    return a*a;
}


int main()
{
    int result;
    result = square(a);   //ERROR

    printf("Square of 4 is %i", result);
    return 0;
}

int a = 4; //DECLARATION AND DEFINITION
```

- Scoping lasts from where a variable or function is **declared**
- What is wrong with the following?

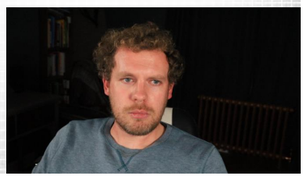
error C2065: 'a' : undeclared identifier

Function Scoping

```c
/* Hello World program */

#include <stdio.h>

int main()
{
    int result, a;
    a = 4;
    result = square(a); //ERROR

    printf("Square of 4 is %i", result);
    return 0;
}

int square(int a)
{
    return a*a;
}
```

- Another example with a function

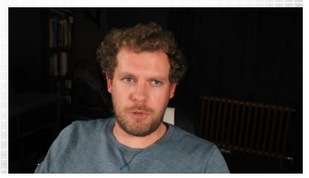
error C2065: 'square' : undeclared identifier



Function Scoping

```c
/* Hello World program */

#include <stdio.h>

int square(int a)
{
    return a*a;
}

int main()
{
    int result, a;
    a = 4;
    result = square(a);

    printf("Square of 4 is %i", result);
    return 0;
}
```

This works but not always practical



Function Declarations

```c
/* Hello World program */

#include <stdio.h>

int square(int);

int main()
{
    int result, a;
    a = 4;
    result = square(a);

    printf("Square of 4 is %i", result);
    return 0;
}

int square(int a)
{
    return a*a;
}
```

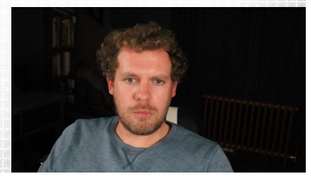
- *A function declaration can be used to forward declare functions*
  - *Sometimes Referred to as a prototype*
  - *Argument names not necessary*
  - *Always considered extern*

A declaration is different to the definition

Variable Declarations

```c
#include <stdio.h>

int square(int);//function declaration
extern int a;   //DECLARATION

int main()
{
    int result;
    result = square(a);

    printf("Square of 4 is %i", result);
    return 0;
}

int a = 4; //DEFINITION

int square(int a)
{
    return a*a;
}
```

- Declarations are not just for functions.
- **`extern`** can be used to declare a variable or function
  - That is defined **elsewhere**
  - **BUT** only defined once



extern

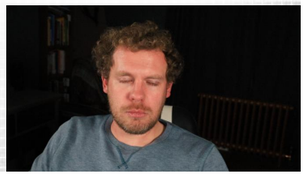
main.c

```c
#include <stdio.h>

//DECLARATIONS
extern int square(int);
extern int a;

int main()
{
    int result;
    result = square(a);

    printf("Square of 4 is %i", result);
    return 0;
}
```

my_maths.c

```c
//DEFINITIONS

int a = 4;

int square(int a)
{
    return a*a;
}
```

- `extern` can declare variables and functions defined in other source modules
  - Resolved by linker



headers

my_maths.h

```c
//DECLARATIONS
extern int square(int);
extern int a;
```

my_maths.c

```c
//DEFINITIONS
#include "my_maths.h"

int a = 4;

int square(int a)
{
    return a*a;
}
```

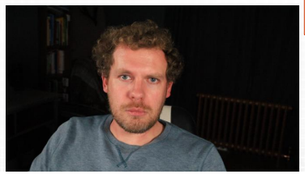
main.c

```c
#include <stdio.h>
//include
#include "my_maths.h"

int main()
{
    int result;
    result = square(a);

    printf("Square of 4 is %i", result);
    return 0;
}
```

other.c

```c
//include
#include "my_maths.h"

int add_a_b_squares(int b)
{
    return square(a) + square(b);
}
```

- Headers can be used to share common declarations



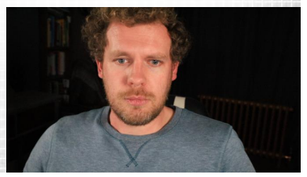
Static

- What is a `static` variable?
  - A static **global** variable or function is visible only in the compilation unit it is defined
    - i.e. No use of `extern` in other source modules
  - A static **local** variable (inside a function) keeps its values between invocations
    - It is defined only once but is declared for lifetime of program

```
void static_test()
{
  int a = 10;
  static int b = 10;
  a += 5;
  b += 5;
  printf("a = %d, sa = %d\n", a, b);
}


int main()
{
  int i;
  for (i = 0; i < 5; ++i)
    static_test();
}
```

```
a = 15, b = ??
a = 15, b = ??
a = 15, b = ??
a = 15, b = ??
a = 15, b = ??
```

What are the values of `b`?



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```
void static_test()
{
  int a = 10;
  static int b = 10;
  a += 5;
  b += 5;
  printf("a = %d, sa = %d\n", a, b);
}


int main()
{
  int i;
  for (i = 0; i < 5; ++i)
    static_test();
}
```

```
a = 15, b = 15
a = 15, b = 20
a = 15, b = 25
a = 15, b = 30
a = 15, b = 35
```

What are the values of `b`?

Summary

- Functions and scoping
  - Differentiate a declaration from a definition
  - Recognise the implications of variable scoping
  - Identify appropriate usage of the keywords `extern` and `static`

- Next lecture: Arrays Strings and IO

Parallel Computing with GPUs

An Introduction to C Part 3 – Arrays Strings and IO

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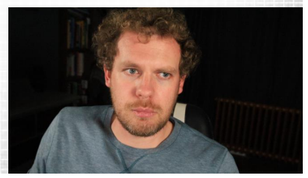

This Lecture (learning objectives)

- Arrays, strings and basic IO
  - Identify definitions of arrays on the stack
  - Select appropriate *formats* to perform effective program input and output
- File IO
  - How to operate on files as streams

Heap vs. Stack

- Stack
  - Memory is managed for you
  - When a function declares a variable it is pushed onto the stack
  - When a function exits all variables on the stack are popped
  - Stack variables are therefore local
  - The stack has size limits (1Mb in VS2017)
- Heap (next lecture)
  - You must manage memory
  - No size restrictions (except available memory)
  - Accessible by any function
- Other
  - Global variables stored in a special data area of memory
  - Program stored in code area of memory

Extra Reading: http://duartes.org/gustavo/blog/post/anatomy-of-a-program-in-memory/

Arrays

- Arrays can be compile time defined using `[size]`
  - Local arrays will be created on the stack (not heap)
  - Multidimensional Arrays possible
- Character Arrays
  - Represent strings
  - String literals can be assigned to an array at declaration only
  - Termination required with `'\0'` character
  - `char *name` is equivalent to `char name []`

```
char my_string1[] = "hello";
char my_string2[6] = "hello";
char my_string3[6] = { 'h', 'e', 'l', 'l', 'o', '\0' };
char *mystring4 = "hello";
static const char mystring5[] = "hello"; //can't be modified

char my_string6[6];
my_string5 = "hello"; //ERROR

char my_string7[5] = "hello" //ERROR
```


Basic IO

- Text Stream abstraction for all input output
  - `stdin`: Standard input
  - `stdout`: Standard output
  - `stderr`: Standard Error
  - `stdin` and `stdout` can be manipulated by;
    - `int getchar();`
    - `int putchar(int c);`

```
#include <stdio.h>
#include <ctype.h>

void main()
{
    int c;
    while ((c = getchar()) != '\n')
        putchar(toupper(c));
}
```

Formatted IO

- Output: `printf`
  - Print (to `stdout`) using formatted string
  - Format specification string and variables
- Input: `scanf`
  - Scans input (from `stdin`) according to format string
  - Saves input to variables in given format
  - Return value is the number of arguments filled
  - Variable argument are pointer to variables (`&`)
    - More on this next lecture…

```
printf("integer variable a value is %d", a);
printf("float variable b value is %f", b);
scanf("%d", &myint);
scanf("%f", &myfloat);
```


String formatting: Common format specifiers

`%[flags][width][.precision][length]specifier`

Specifier	Output	Example
`d or I (lld)`	Signed integer (long long signed integer)	123, -123
`U (llu)`	Unsigned integer (long long unsigned integer)	123
`x or X`	Unsigned hexadecimal integer (X uppercase)	1c4, 1C4
`f`	Decimal floating point	123.456
`e or E`	Scientific notation (E uppercase)	6.64e+2, 6.64E+2
`c`	character	A
`s`	Terminated string of characters	character string

Flag	Description
–	Left justify given width
+	Forces use of + or - sign
0	Left pads the number with zeros (0)

.precision	Description
`.number`	For `d`, `u` or `i` to minimum number of digits For `f` and `e` the number of decimal places after decimal point

String Formatting Escape Characters

Escape Sequence	Character represented
\a	Alarm beep (system beep)
\b	Backspace
\f	Formfeed (new page), e.g. new page in terminal
\n	New line or line feed
\r	Carriage return
\t	Horizontal tab
\\	Backslash
\’ or \” or \?	Single or double quotes or question mark

Formatting examples

```
printf("\t%0.4d\n", 1);

printf("\t%0.4d\n", 12345678);

printf("%d\n", (int)1.23456);

printf("%d\n", sizeof(1.95f));
```

What will each of the following output?

Formatting examples

```
printf("\t%0.4d\n", 1);

printf("\t%0.4d\n", 12345678);

printf("%d\n", (int)1.23456);

printf("%d\n", sizeof(1.95f));
```

```
        0001
        12345678
1
4
```

What will each of the following output?

IO example

- A basic calculator for summing inputs

```
#include <stdio.h>

int main()
{
    int a, sum;
    sum = 0;

    while (scanf("%d", &a) == 1)
        printf ("\tsum:%0.8d\n", sum += a);

    return 0;
}
```

Formatted string input and output

- sprintf
  - The same as `printf` but operates on a character array
- sscanf
  - The same as `scanf` but operates on a character array

```
char s1[] = "COM4521";
int module;
char buffer[32];

sscanf(s1, "COM%d", &module);
sprintf(buffer, "COM%d is awesome!", module);
```

Files

- Files are still a stream
  - `FILE* fopen(char *name, char *mode);`
    - Mode: “r” = read, “w” = write, “a” = append, “b” = binary, “+” = open for update
  - `int fclose(FILE *file);`

Ignore this (*) operator for now….

```
#include <stdio.h>
#include <string.h>

void main()
{
    FILE *f = NULL;
    f = fopen("myfile.txt", "r");

    if (f == NULL){
        fprintf(stderr, "Could not open file\n");
    } else {
        fclose(f);
    }
}
```

File reading and writing of strings

- By character
  - `int getc(FILE *file);` same as `getchar` but on a file stream
  - `int putc(int c, FILE * file);` same as `putchar` but on file stream
- By formatted lines
  - `int fscanf(FILE *f, char *format, …);`
  - `int fprintf(FILE *f, char *format, …);`

```
void filecopy(FILE* f1, FILE *f2)
{
    int c;
    while (c = getc(f1) != EOF)
        putc(c, f2);
}
```

String Coversions

- `#include <stdlib>`
- `atof`: convert to float
- `atoi`: convert to int
- `strtod`: convert to double
- `strtoul`: convert to unsigned long

```
char *x = "450";

int result = atoi(x);

printf("integer value of the string is %d\n", result);
```

This Lecture (learning objectives)

- Arrays, strings and basic IO
  - Identify definitions of arrays on the stack
  - Select appropriate *formats* to perform effective program input and output
- File IO
  - How to operate on files as streams

Character array operations

```
char str1[20];
char str2[20];
strcpy(str1, "To be ");
strcpy(str2, "or not to be");
strncat(str1, str2, 6);
```

- `#include <string.h>`
- Copying
  - `char * strcpy ( char * destination, const char * source );`
- Compare
  - `int strcmp ( const char * str1, const char * str2 );`
  - Returns 0 if equal
- Concatenate
  - `char * strcat ( char * destination, const char * source );`
- Length
  - `size_t strlen ( const char * str );`
  - `size_t` is an unsigned integer of at least 16 bits
- `n` versions
  - Each function has a version which performs the operation up to `num` char
  - E.g. `strncpy`, `strncmp`, `strncat` all take an extra argument (…`size`