Developing Soft and Parallel Programming Skills Using Project-Based Learning
Fall 2019
Team CHABU
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1. Planning and Scheduling

Work Breakdown

Assignee Name	Email	Task	Duration (Hours)	Dependency	Due Date	Note
Harsh Jivani	hjivani1@student.gsu.edu	Slack, Parallel Programming	2 hours	None	09/30/19	
Chris Lavey	clavey@student.gsu.edu	Technical writing (getting the report ready) as described in the assignment, Parallel Programming	5 hours	Slack, Github, Parallel Programming, ARM Assembly Programming	10/03/19	
Anggiela Yupanqui **(coordinator)**	ayupanquirojas1@student.gsu.edu	GitHub, ARM Assembly Programming	2 hours	None	09/30/19	
Ugonma Nnakwe	unnakwe1@student.gsu.edu	Video editing, ARM Assembly Programming	5 hours	Video recording	10/03/19	
Binh Le	ble8@student.gsu.edu	Parallel Programming	2 hours	None	09/30/19	

2. Parallel Programming Skills

2.1 Foundation

2.1.1. Components of Raspberry PI B+

2.1.1.1. CPU

The central processing unit acts as the brain of the unit, and is involved in all tasks that take input, perform calculations, and produce output. The CPU is a Broadcom BCM2837B0, which is 64-bit and has a clock speed of 1.4GHz.

2.1.1.2. GPU

The graphics processing unit handles output of graphics to a display.

2.1.1.3. 40-Pin Header

These are the exposed general-purpose input/output connection pins that are used to connect external hardware components.

2.1.1.4. 3.55mm Audio/Composite Output Jack

This is used to connect an external sound device to the Raspberry PI, such as speakers. The Raspberry PI is not capable of receiving audio input.

2.1.1.5. 2x2 USB 2.0 Ports

These are used to connect peripherals such as a mouse and keyboard. If necessary, a USB hub can be used to connect more outside peripherals.

2.1.1.6. HDMI Port

This is used to connect to an outside display via a standard HDMI cable.

2.1.1.7. Micro USB Port

This is where you plug in the power cable for the PI. The PI comes with a 5V, 2.5A micro USB power connector.

2.1.1.8. MIPI CSI Port

This allows a small camera to be connected to the CPU.

2.1.1.9. MIPI DSI Port

This is used by an integrated circuit to feed graphics data to the display

2.1.1.10. Micro SD Card Slot

This is where a Micro SD Card is inserted. The card acts as storage for the PI. The PI will not boot if the card doesn't have an OS installed.

2.1.1.11. Ethernet Port

This is used to connect the PI to a wired network via an Ethernet cable. It is capable of having Internet speeds of up to 300Mbps.

2.1.1.12. PoE Pin Header and PoE HAT

This allows the system to be powered by an Ethernet cable.

2.1.2. Number of Cores on Raspberry PI B+

All Raspberry Pi 3's have a quad-core CPU. The specific type and clock speed is listed above.

2.1.3. X86 (CISC) vs. ARM (RISC)

2.1.3.1. Instruction Set

X86 processors are called Complex Instruction Set Computing processors, which means that the instruction set allows for more complex instructions to access memory. This means a X86 processor will be less dependent on registers, as it will be able to much more easily access external storage.

2.1.3.2. Speed of Calculation

Due to the instruction set being more complex, X86 processors generally require more clock cycles to perform calculations when compared to ARM processors.

2.1.3.3. Writing Software

Due to the instruction set being less complex, coding for ARM processors puts a larger strain on the programmer to write as efficiently as possible when compared to coding for X86 processors.

2.1.4. Sequential vs. Parallel

During parallel computation, the CPU distributes a single process to each core to handle multiple computations at once. During sequential computation, the CPU handles each task individually and computes them sequentially. Sequential programs tend to be easier to program, and for simple programs or tasks that don't require high efficiency it should be fine. When a program is designed to handle large amounts of data or needs to perform many calculations quickly and efficiently, parallel programming is a much better option.

2.1.5. Data and Task Parallelism

The general form of a program that's designed to be run in parallel must accomplish three things. It must break apart the tasks so that they can be executed simultaneously. It must be able to multitask at any given time. Lastly, it must be proficient because it utilizes multiple computer resources rather than a single one.

2.1.6. Processes vs. Threads

A process is the act of running a program, while a thread is how a program is divided into smaller parts in order to be executed.

2.1.7. OpenMP

OpenMP is a guideline used by compilers. It is comprised of pragmas which act as directives for the compiler to generate threaded code.

2.1.8. Applications of Multi-core

Many applications benefit from using multi-core CPUs, including but not limited to database servers, web servers, multimedia applications, and scientific applications such as CAD and CAM.

2.1.9. Why Multi-core?

Multi-core processors allow for much higher clock speeds compared to single-core processors. Multi-core processors have deeply pipelined circuits which are difficult to design and can have heat problems if not cooled properly. Many applications are multithreaded to increase efficiency, and there has been a general trend in computer architecture towards more parallelism.

2.2. Parallel Programming Basics

For the parallel programming portion of this project, we were tasked with editing a C program that prints a string followed by a number identifying them from a group of four threads. Below is the edited code:

```
 GNU nano 2.3.1                File: spmd2.c

#include <stdio.h>
#include <omp.h>
#include <stdlib.h>
int main(int argc,char** argv) {
//int id, numThreads;
printf("\n");
if (argc > 1) {
omp_set_num_threads( atoi(argv[1]));
}
#pragma omp parallel
{
int id = omp_get_thread_num();
int numThreads = omp_get_num_threads();
printf("Hello from thread %d of %d\n",id,numThreads);
}
printf("\n");
return 0;
}
```

Prior to revision, line 5 was not commented out, and within **#pragma omp parallel** *id* and *numThreads* were not declared as **int** data types. When compiled and ran, the program printed out something similar to this:

Hello from thread 1 of 4
Hello from thread 2 of 4
Hello from thread 1 of 4
Hello from thread 2 of 4

This was a problem, as each thread ID should have been unique. The error with this program was that the variable we were wishing to access was declared outside the parallel function, meaning that all the threads shared those variables. To fix this issue, we commented out the initial declaration in line 5 and declared *id* and *numThreads* as the **int** data type. Once we saved, compiled, and ran our program, this was the resulting output:

```
[hjivani1@gsuad.gsu.edu@snowball ~]$ ./spmd2 4

Hello from thread 0 of 4
Hello from thread 3 of 4
Hello from thread 2 of 4
Hello from thread 1 of 4

[hjivani1@gsuad.gsu.edu@snowball ~]$ ./spmd2 4

Hello from thread 2 of 4
Hello from thread 3 of 4
Hello from thread 1 of 4
Hello from thread 0 of 4

[hjivani1@gsuad.gsu.edu@snowball ~]$
```

This output was what we expected from a multithreaded program. Each string was printed via a unique thread, and there were no duplicates. This is because in the revised program, the *id* and *numThreads* were declared for each thread, meaning that each thread had a unique *id*.

3. ARM Assembly Programming

3.1. Part 1

In part 1 of the ARM Assembly Programming portion of this project, we were tasked with writing a program **second.s** based on a given program and examining the output. Below is a screenshot of the code:

```
a: .word 2
b: .word 5
c: .word 0
.section .text
.globl _start
_start:
        ldr r1, =a
        ldr r1, [r1]
        ldr r2, =b
        ldr r2, [r2]
        add r1, r1, r2
        ldr r2, =c
        str r1, [r2]

        mov r7, #1
        svc #0
.end
```

This program begins by loading **r1** with the memory address of **a** and then loading **a** into **r1**, resulting in the value of **r1** becoming 2. It then repeats this process with **r2** and

b, resulting in **r2** having a value of 5. It then adds **r1** to **r2** and stores the output to **r1**, meaning the value stored in **r1** was now 7. It then loads the memory address of **c** into **r2**. It finishes by storing the value of **r1**, 5, into **c**, making the value stored in **c** 7.

When we assemble, link, and run this program, there is no output to the terminal as there was never an instruction to print the result to the console. To see the values of the registers at the end of our program, we had to debug our program in a similar manner to our program in Project 1.

Once we had our program in the debugger, we set a breakpoint at line 13, as this was the last line before the program terminated. Below is the output of **info registers**:

```
(gdb) b 13
Breakpoint 1 at 0x10078: file second.s, line 13.
(gdb) run
Starting program: /home/pi/second

Breakpoint 1, _start () at second.s:13
13              str r1, [r2]
(gdb) info registers
r0             0x0                0
r1             0x7                7
r2             0x1005c            65628
r3             0x0                0
r4             0x0                0
r5             0x0                0
r6             0x0                0
r7             0x0                0
r8             0x0                0
r9             0x0                0
r10            0x0                0
r11            0x0                0
r12            0x0                0
sp             0x7efff3c0         0x7efff3c0
lr             0x0                0
pc             0x10078            0x10078 <_start+24>
cpsr           0x10               16
fpscr          0x0                0
(gdb)
```

From this screen, we can tell that the final value of **r1** is 7 like we intended, but we have no way of identifying whether the final value of **c** is valid from this screen. To get information about the memory at the breakpoint, we use the command **x** followed by modifiers to determine the type and the address of the line we're interested in, which in this case is **0x10078**. After using the command **x/3xw** 0x**10078** in the debugger, this is the output:

```
(gdb) b 18
Breakpoint 1 at 0x10098: file arithmetic2.s, line 18.
(gdb) run
Starting program: /home/pi/arithmetic2

Breakpoint 1, _start () at arithmetic2.s:18
18              str r1,[r1]
(gdb) stepi

Program received signal SIGSEGV, Segmentation fault.
_start () at arithmetic2.s:18
18              str r1,[r1]
(gdb) x/3xw 0x10098
0x10098 <_start+36>:    0xe5811000      0xe3a07001      0xef000000
(gdb)
```

By using this command, we see see the values of the first three words at that address in hexadecimal format. We are interested in **c**, so that would be the third value. By converting this number from hexadecimal to decimal, we see that the value stored in **c** is 7.

3.2. Part 2

For the second portion of ARM Assembly programming for this project, we were tasked with writing a new program, based on what we learned from **second.s**, to produce the following output:

Register = val2 + val3 +9 - val1

To do this, we use the following program:

```
.section .data
val1: .word 6
val2: .word 11
val3: .word 16

.section .text
.globl _start
_start:
        ldr r1,=val2
        ldr r1,[r1]
        ldr r2,=val3
        ldr r2,[r2]
        add r1,r1,r2
        add r1,r1,#9
        ldr r3,=val1
        ldr r3,[r3]
        sub r1,r1,r3
        str r1,[r1]

        mov r7,#1
        svc #0
.end
```

This program begins by declaring three variables in the **.data** section: **val1**, **val2**, and **val3**. They are all of the **.word** data type, with **val1** having a value of 6, **val2** having a value of 11, and **val3** having a value of 16, as specified by the documents. We start the program itself by loading **val2** into **r1** in a similar manner to part 1 of this exercise. We load **r2** with **val3**, and then we add **r1** to **r2** and store the value in **r1**, making the current value of **r1** 27. We then add 9 to **r1** and store this value in **r1**, making the value of **r1** 36. We then load **r3** with the value of **val1**, then we subtract **r3** from **r1** and store the result in **r1**, making the final value of **r1** 30.

After assembling and linking the program, we ran it, and as expected there was no output to the console. We then proceeded to debug **arithmetic2.s** using the GDB debugger. Once the program was in the debugger, we set a breakpoint at line 21 and used the command **info registers** to display register values. This was the result:

```
(gdb) b 18
Breakpoint 1 at 0x10098: file arithmetic2.s, line 18.
(gdb) run
Starting program: /home/pi/arithmetic2

Breakpoint 1, _start () at arithmetic2.s:18
18              str r1,[r1]
(gdb) info registers
r0             0x0                 0
r1             0x1e                30
r2             0x10                16
r3             0x6                 6
r4             0x0                 0
r5             0x0                 0
r6             0x0                 0
r7             0x0                 0
r8             0x0                 0
r9             0x0                 0
r10            0x0                 0
r11            0x0                 0
r12            0x0                 0
sp             0x7efff3b0          0x7efff3b0
lr             0x0                 0
pc             0x10098             0x10098 <_start+36>
cpsr           0x10                16
fpscr          0x0                 0
```

This showed that the values stored within **r1**, **r2**, and **r3** were as we expected, and as such we were done with the programming portion of this assignment.

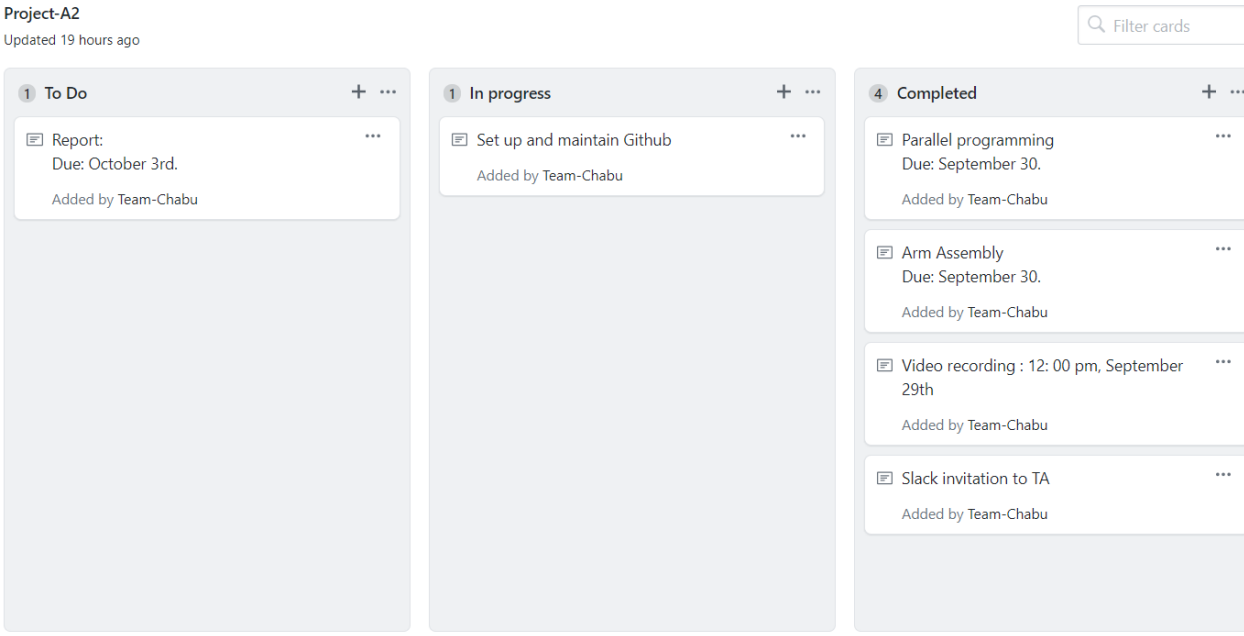
4. Appendix

4.1. Github

4.1.1. Link:

https://github.com/Team-Chabu/CSC3210-CHABU

4.1.2. Screenshot:



4.2. Slack

https://join.slack.com/t/csc-3210-teamchabu/shared_invite/enQtNzc0ODEwMjkyNjU2LTU4MGQ2MzcyMDg5YTJhMjc4ZmZjZWU4OTgzNjk4NzI1M2ZjMjY5YjBiMjYyMTgyOGVmNGQzMjFhMjYzN2YxOWM

4.3. Youtube (Channel)

https://www.youtube.com/channel/UCp-0kVA08dU4F79t6slHtLQ

4.4. Youtube (Video)

https://youtu.be/rdZswfgQoh4