

Developing Soft and Parallel Programming Skills using Project-Based Learning

Spring 2020

The Commuters

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**Planning and Scheduling:**

Assignee Name	Email	Task	Duration (hours)	Dependency	Due Date	Note
Alaya Shack	ashack1@student.gsu.edu	Create the planning and scheduling table. Complete individual parallel programming skills task and ARM assembly programming task.	3 hours	(none)	02/19	Review report for grammatical/spelling errors.
Miguel Romo (Coordinator)	mrromo1@student.gsu.edu	Edit the video and include the link in the report. Complete individual parallel programming skills task and ARM assembly programming task.	1.5 hours	(none)	02/19	Review report for grammatical/spelling errors.
Joan Galicia	jgalicia2@student.gsu.edu	Serve as the facilitator. Complete individual parallel programming skills task and ARM assembly programming task.	2 hours	(none)	02/19	Review report for grammatical/spelling errors.

Arteen Ghafourikia	aghafourikia1@ student.gsu.edu	Identify new To-do, In-progress, and Completed columns in Github. Get the report formatted correctly (fonts, page numbers, and sections). Complete individual parallel programming skills task and ARM assembly programming task.	4 hours	Github, each member's report, and the video.	02/20	24 hours before the due date, please have the report ready for all team members to review.
Andre Nguyenphuc	anguyenphuc1 @student.gsu.edu	Send an invitation to teaching assistant through slack. Complete individual parallel programming skills task and ARM assembly programming task.	2 hours	(none)	02/19	Review report for grammatical/ spelling errors.

### **Parallel Programming Skills Foundation: Alaya Shack**

#### **→ Identifying the components of the raspberry PI B+.**

- ◆ The components of the raspberry PI B+ include a single board computer with a quad-core multicore CPU that has 1GB of RAM, two USB ports, an ethernet port, an ethernet controller, two power sources, a HDMI port, a camera, and display.

#### **→ How many cores does the Raspberry Pi's B+ CPU have?**

- ◆ The Raspberry Pi's B+ CPU is quad core, which means it has four cores.

#### **→ List three main differences between X86 (CISC) and ARM Raspberry PI (RISC). Justify your answer and use your own words.**

- ◆ One main difference between CISC and RISC is the instruction set. CISC has a larger instruction set and a vast amount of options and more functional capabilities in its instruction set, which allows more complex instructions to access memory. In RISC, the instruction set contains 100 or less instructions. Therefore, RISC has more registers, but CISC has more operations, addressing modes, and less registers.
- ◆ Another difference is that ARM architecture (after version 3) changed to BI-endian, which has a feature that allows you to switch between big endian and little endian, but X86 uses the little-endian format.
- ◆ RISC uses instructions that operate only on registers and only load/store instructions can access memory, which means it typically takes more lines of code and instructions to complete the desired task. However, CISC allows for a reduction in the amount of code and instructions needed to perform the desired task because direct access to memory is allowed.

#### **→ What is the difference between sequential and parallel computation and identify the practical significance of each?**

- ◆ In sequential computation, instructions are executed one after another, and only one instruction may execute at any moment in time. However, with parallel computation, instructions can be executed at the same time on different processors at any moment.
- ◆ Sequential/serial computation is what software has traditionally been written for, but sequential computation can be impractical for solving larger problems. This is where parallel computation is more efficient because it is able to decrease the time needed to solve the problem because more resources are used at once to solve the problem.

#### **→ Identify the basic form of data and task parallelism in computational problems.**

- ◆ Data parallelism is when there are multiple data items, and the same computation is performed to the items. In this form, the data will be divided up among multiple processors and each processor will perform the same computation.
- ◆ Task parallelism is when there are multiple data items, but there are different computations or "tasks" needed to be performed to the items. In this form, the data will be divided up among processors, and each processor will perform a different computation.

#### **→ Explain the differences between processes and threads.**

- ◆ One main difference between processes and threads are that processes do not share memory with each other, while threads share the common memory of the process that they belong to.
- ◆ Also, a process is an abstraction of a program in execution. However, a thread is a type of process that is said to be a lightweight process that allows a process to be decomposed into smaller parts.

→ **What is OpenMP and what is OpenMP pragmas?**

- ◆ OpenMP is a standard that compilers who implement it must adhere to, and it provides support for parallel-programming in environments where memory is shared. In OpenMP, the library handles thread creation and management to make the programmer's life easier, by making their work less error-prone.
- ◆ OpenMP pragmas are compiler directives that enable the compiler to generate threaded code.

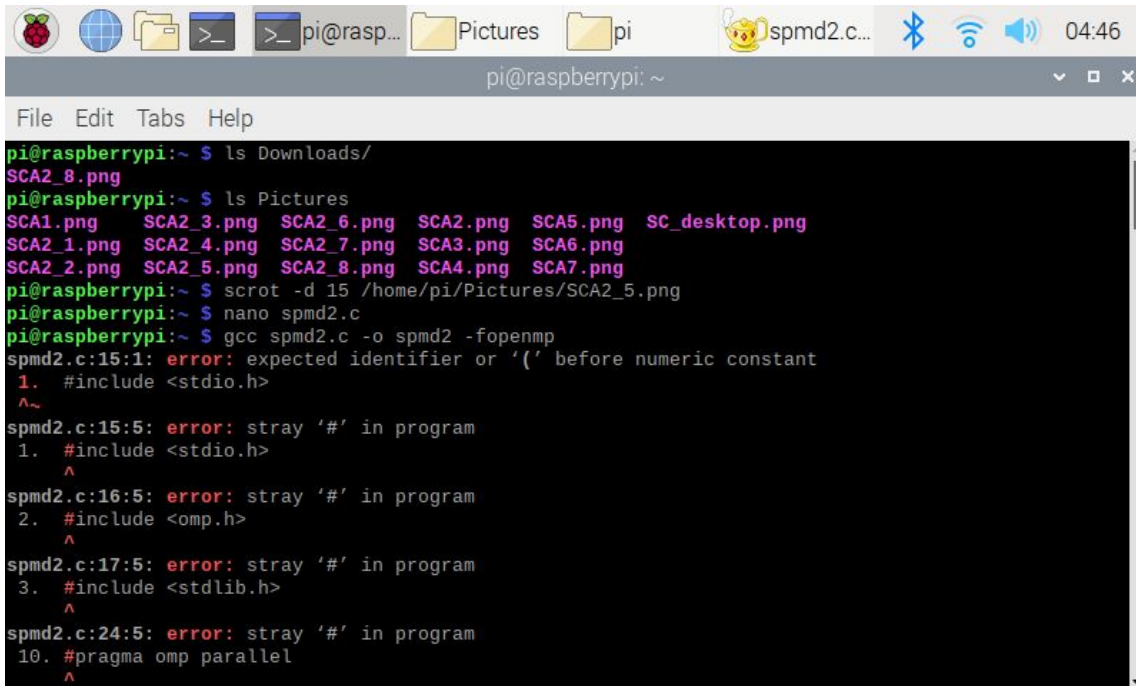
→ **What applications benefit from multi-core (list four)?**

- ◆ Some applications that benefit from multi-core are:
  - Database servers
  - Compilers
  - Multimedia applications
  - Scientific applications such as CAD/CAM.

→ **Why Multicore? (why not single core, list four)**

- ◆ These are some of the reasons why multi-core is preferred over single-core:
  - It is difficult to make single-core clock frequencies higher.
  - There is a general trend in computer architecture toward more parallelism, thus one should want to keep with current times.
  - The more cores that a CPU has results in the OS executing more processes at once, which increases the throughput of a system.
  - Multi-cores increase the clock speed of the processor without having as many heat problems that single cores have when trying to increase their clock speed.

## Parallel Programming Basics: Alaya Shack

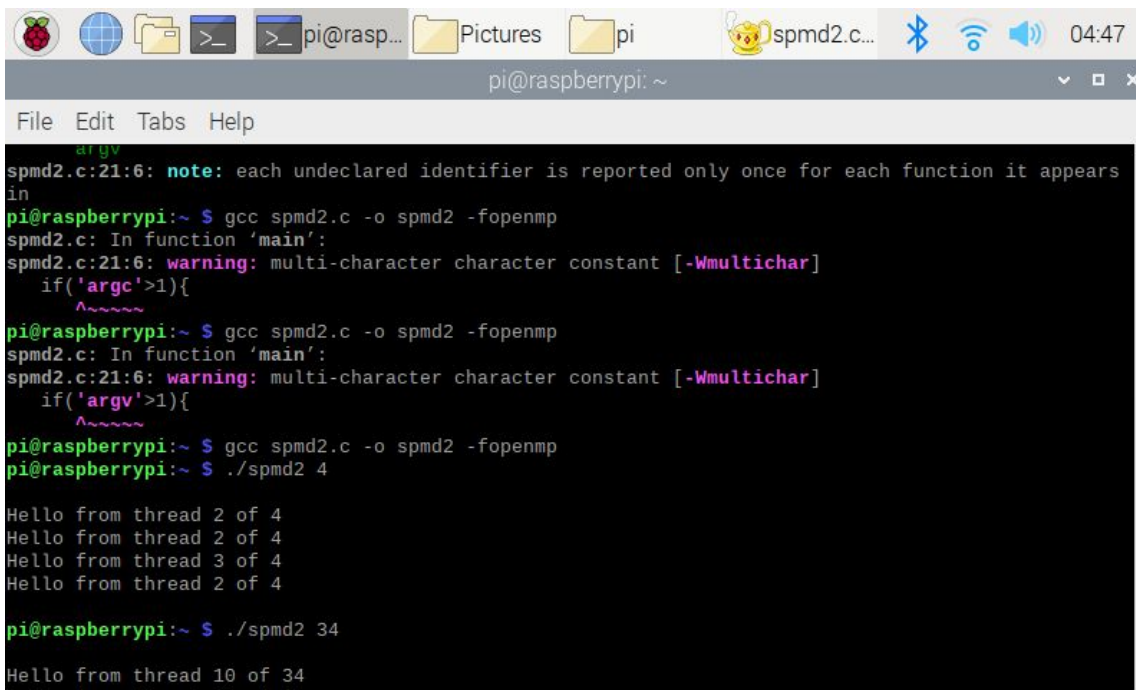


```

pi@raspberrypi:~ $ ls Downloads/
SCA2_8.png
pi@raspberrypi:~ $ ls Pictures
SCA1.png  SCA2_3.png  SCA2_6.png  SCA2.png  SCA5.png  SC_desktop.png
SCA2_1.png  SCA2_4.png  SCA2_7.png  SCA3.png  SCA6.png
SCA2_2.png  SCA2_5.png  SCA2_8.png  SCA4.png  SCA7.png
pi@raspberrypi:~ $ scrot -d 15 /home/pi/Pictures/SCA2_5.png
pi@raspberrypi:~ $ nano spmd2.c
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
spmd2.c:15:1: error: expected identifier or '(' before numeric constant
1. #include <stdio.h>
   ^
spmd2.c:15:5: error: stray '#' in program
1. #include <stdio.h>
   ^
spmd2.c:16:5: error: stray '#' in program
2. #include <omp.h>
   ^
spmd2.c:17:5: error: stray '#' in program
3. #include <stdlib.h>
   ^
spmd2.c:24:5: error: stray '#' in program
10. #pragma omp parallel
    ^

```

This screenshot uses the terminal trick, tab completion of long names. I tried the trick with ls Dow[Tab], and I tried it with ls Pic[Tab]. It filled in the remaining part of the directories, and it listed all the items that belong in that directory. Also, in this screenshot, I used “gcc spmd2.c -o spmd2 -fopenmp” to make the program executable, but I had errors.

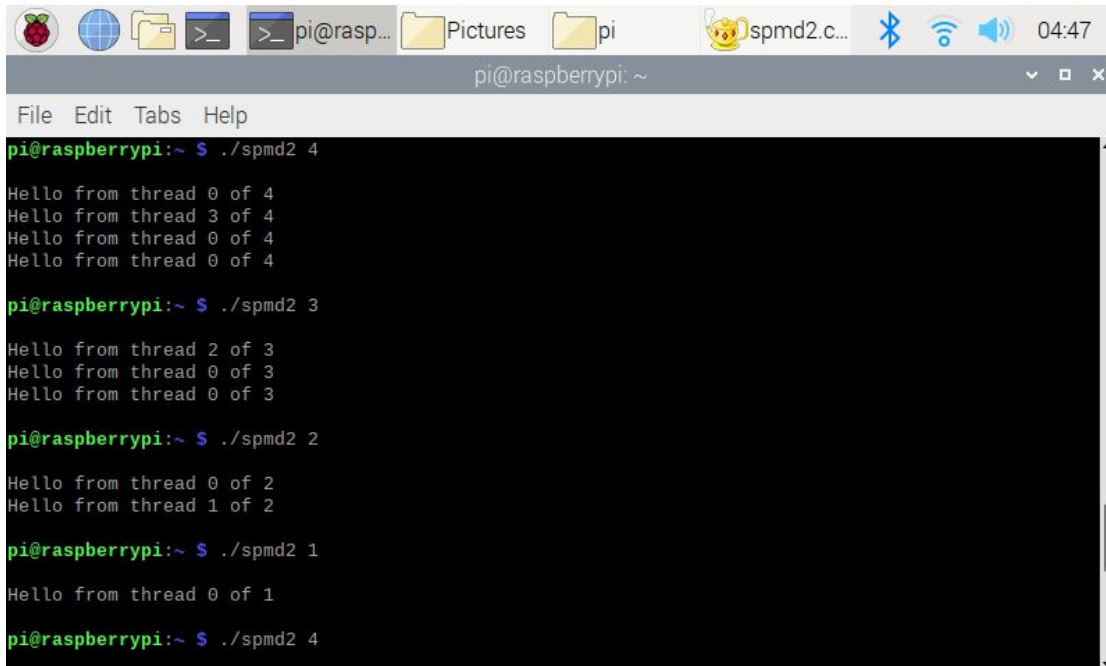


```

spmd2.c:21:6: note: each undeclared identifier is reported only once for each function it appears in
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
spmd2.c: In function 'main':
spmd2.c:21:6: warning: multi-character character constant [-Wmultichar]
    if('argc'>1){
       ^~~~~~
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
spmd2.c: In function 'main':
spmd2.c:21:6: warning: multi-character character constant [-Wmultichar]
    if('argv'>1){
       ^~~~~~
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 2 of 4
Hello from thread 2 of 4
Hello from thread 3 of 4
Hello from thread 2 of 4
pi@raspberrypi:~ $ ./spmd2 34
Hello from thread 10 of 34

```

In this screenshot, I typed the same command to make the program executable. After I fixed my errors, I was finally able to make the `spmd2.c` an executable program. Then, I typed “`./spmd2 4`” to run the program.



```
pi@raspberrypi: ~  
File Edit Tabs Help  
pi@raspberrypi:~ $ ./spmd2 4  
Hello from thread 0 of 4  
Hello from thread 3 of 4  
Hello from thread 0 of 4  
Hello from thread 0 of 4  
pi@raspberrypi:~ $ ./spmd2 3  
Hello from thread 2 of 3  
Hello from thread 0 of 3  
Hello from thread 0 of 3  
pi@raspberrypi:~ $ ./spmd2 2  
Hello from thread 0 of 2  
Hello from thread 1 of 2  
pi@raspberrypi:~ $ ./spmd2 1  
Hello from thread 0 of 1  
pi@raspberrypi:~ $ ./spmd2 4
```

In this screenshot, I kept typing “`./spmd2 4`”, but I alternated the 4 with 3, 2, and 1. I learned that the 4 is a command-line argument that indicates how many threads to fork and that it can be changed. When I changed the argument, I noticed that the message printed the amount of times that the argument was. Also, I noticed that some of the messages would print the thread id multiple times and that the numbers do not always print out in order.

```

GNU nano 3.2 spmd2.c
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;
}

```

This screenshot is of the adjustments that were made to make the program run properly. First, I had to make line 5 a comment by placing two backslashes at the front of the line. Also, for lines 12 and 13, I had to properly declare the variable by placing “int” in front of the lines because the variables are of type integer.

```

pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 2 of 4
Hello from thread 0 of 4
Hello from thread 3 of 4
Hello from thread 1 of 4

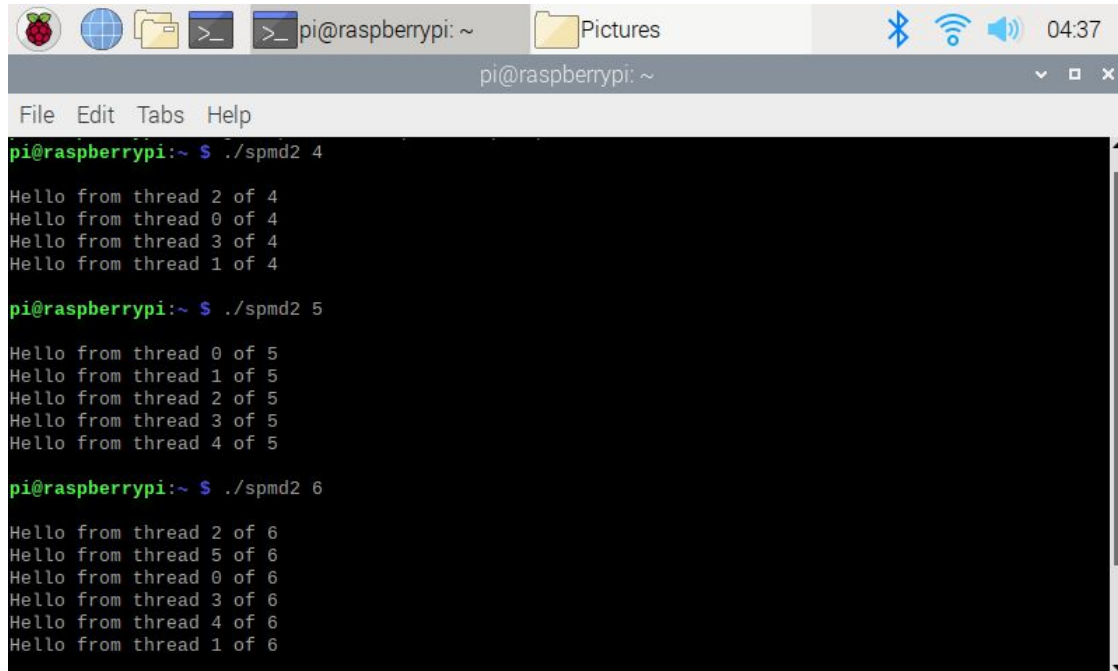
pi@raspberrypi:~ $ ./spmd2 5
Hello from thread 0 of 5
Hello from thread 1 of 5
Hello from thread 2 of 5
Hello from thread 3 of 5
Hello from thread 4 of 5

pi@raspberrypi:~ $ ./spmd2 6
Hello from thread 2 of 6
Hello from thread 5 of 6
Hello from thread 0 of 6
Hello from thread 3 of 6
Hello from thread 4 of 6
Hello from thread 1 of 6

```

In this screenshot, I made the changes to the code. I typed “gcc spmd2.c -o spmd2 -fopenmp” to compile the program, and I ran the program with “./spmd2 4”.





The screenshot shows a terminal window titled 'pi@raspberrypi: ~' with a menu bar (File, Edit, Tabs, Help) and a status bar (Bluetooth, Wi-Fi, Speaker, 04:37). The terminal displays the output of three commands: `./spmd2 4`, `./spmd2 5`, and `./spmd2 6`. Each command produces a list of messages from threads, with thread IDs ranging from 0 to 4, 0 to 5, and 0 to 5 respectively. The messages are not in order, indicating concurrent execution.

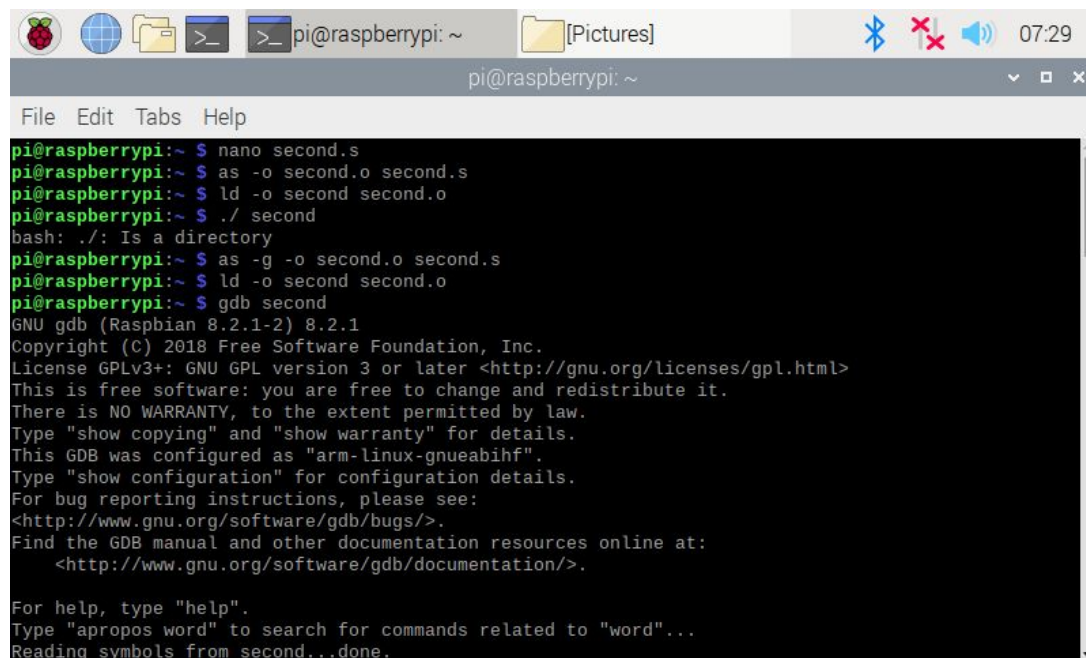
```
pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 2 of 4
Hello from thread 0 of 4
Hello from thread 3 of 4
Hello from thread 1 of 4

pi@raspberrypi:~ $ ./spmd2 5
Hello from thread 0 of 5
Hello from thread 1 of 5
Hello from thread 2 of 5
Hello from thread 3 of 5
Hello from thread 4 of 5

pi@raspberrypi:~ $ ./spmd2 6
Hello from thread 2 of 6
Hello from thread 5 of 6
Hello from thread 0 of 6
Hello from thread 3 of 6
Hello from thread 4 of 6
Hello from thread 1 of 6
```

In this screenshot, I alternated the command-line argument 4 with 5 and 6 to make sure that the program was running correctly. The program was running correctly because now the thread id number only appears once. Although the thread id numbers do not print in order, I learned that this is okay because we do not know when a thread will finish.

## Arm Assembly Programming:Alaya Shack

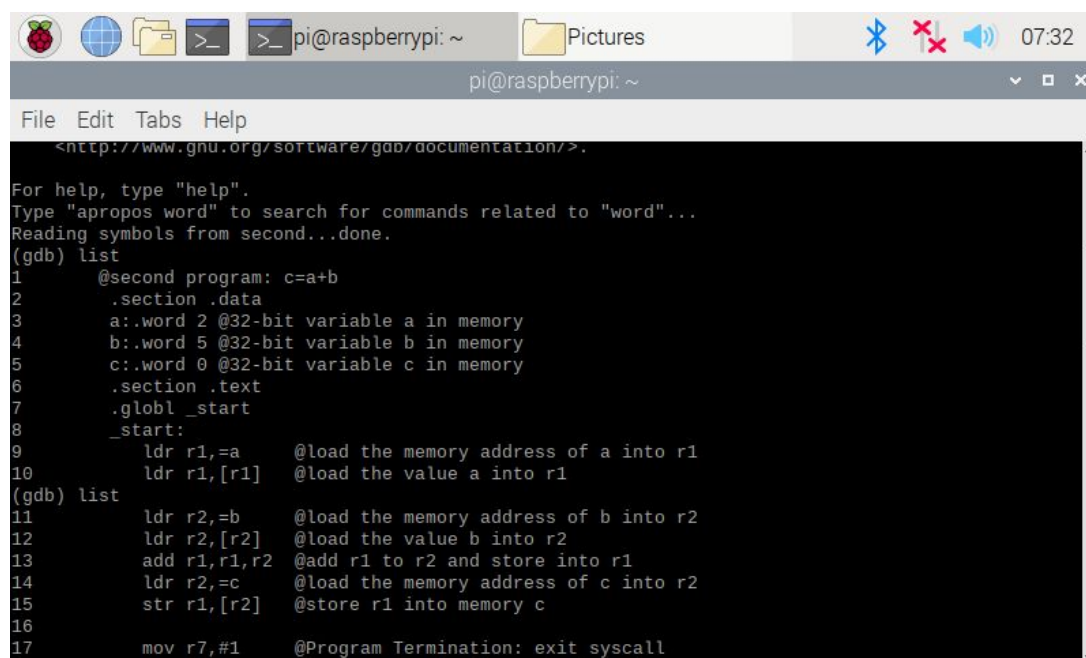


```

pi@raspberrypi: ~
File Edit Tabs Help
pi@raspberrypi:~ $ nano second.s
pi@raspberrypi:~ $ as -o second.o second.s
pi@raspberrypi:~ $ ld -o second second.o
pi@raspberrypi:~ $ ./ second
bash: ./: Is a directory
pi@raspberrypi:~ $ as -g -o second.o second.s
pi@raspberrypi:~ $ ld -o second second.o
pi@raspberrypi:~ $ gdb second
GNU gdb (Raspbian 8.2.1-2) 8.2.1
Copyright (C) 2018 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "arm-linux-gnueabi".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from second...done.
  
```

This screenshot shows how I started the “second” file with “nano second.s”. Once, I finished writing the file I was able to assemble and link the second program. I typed “./ second” to run the program, as directed by the assignment, and the “bash: ./: Is a directory” message appeared. However, I tried the “./second” and I did not get any output, which is what I expected. The second time that I assembled and linked the program, I added the “-g” flag for debugging. Then, I typed the “gdb second” command to launch the debugger.



```

pi@raspberrypi: ~
File Edit Tabs Help
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from second...done.
(gdb) list
1      @second program: c=a+b
2      .section .data
3      a:.word 2 @32-bit variable a in memory
4      b:.word 5 @32-bit variable b in memory
5      c:.word 0 @32-bit variable c in memory
6      .section .text
7      .globl _start
8      _start:
9          ldr r1,a      @load the memory address of a into r1
10         ldr r1,[r1]   @load the value a into r1
(gdb) list
11         ldr r2,b      @load the memory address of b into r2
12         ldr r2,[r2]   @load the value b into r2
13         add r1,r1,r2  @add r1 to r2 and store into r1
14         ldr r2,c      @load the memory address of c into r2
15         str r1,[r2]   @store r1 into memory c
16
17         mov r7,#1     @Program Termination: exit syscall
  
```

In this screenshot, I used the “gdb list” command to list the first ten lines of code, and I repeated the command and listed the next ten lines of code for the second program.

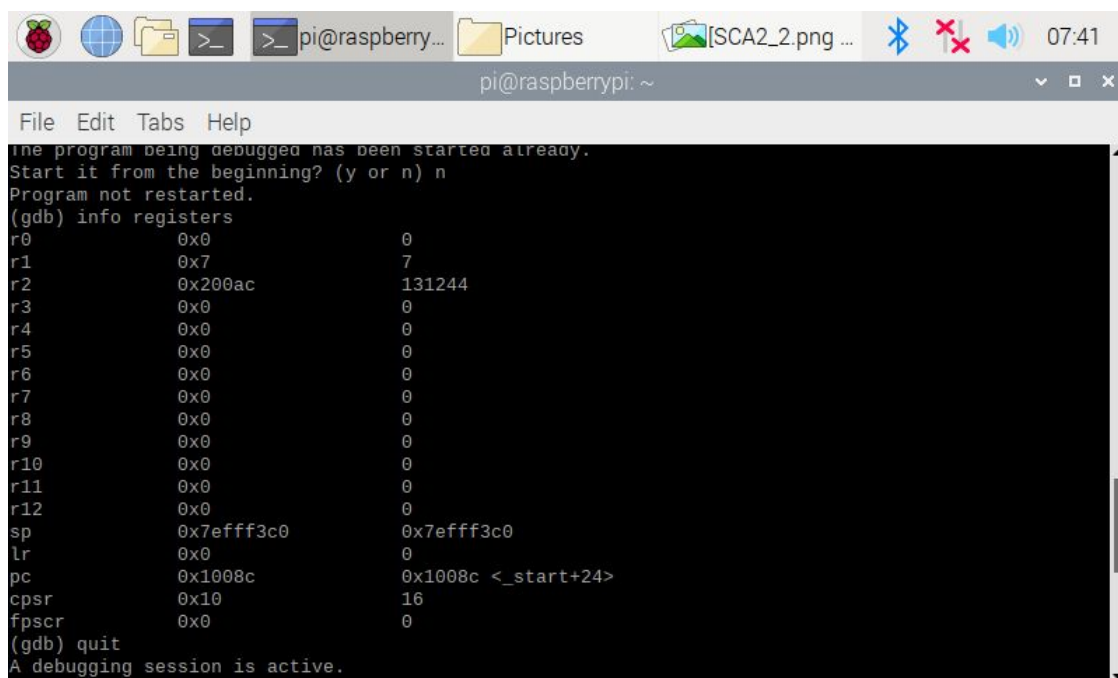
```

pi@raspberrypi: ~
File Edit Tabs Help
15      str r1,[r2]    @store r1 into memory c
16
17      mov r7,#1      @Program Termination: exit syscall
18      svc #0         @Program Termination:wake kernel
19      .end
(gdb) b 15
Breakpoint 1 at 0x1008c: file second.s, line 15.
(gdb) run
Starting program: /home/pi/second

Breakpoint 1, _start () at second.s:15
15      str r1,[r2]    @store r1 into memory c
(gdb) stepi
17      mov r7,#1      @Program Termination: exit syscall
(gdb) stepi
18      svc #0         @Program Termination:wake kernel
(gdb) x/3xw 0x8054
0x8054: Cannot access memory at address 0x8054
(gdb) x/3xw 0x1008c
0x1008c <_start+24>:  0xe5821000    0xe3a07001    0xef000000
(gdb) x/3xw 0x8054
0x8054: Cannot access memory at address 0x8054
(gdb) run
The program being debugged has been started already.
start of program from the beginning? (y or n)

```

This screenshot shows where I inserted a breakpoint at line 15. After I inserted the breakpoint, I noticed that the next line shows the memory address of where I inserted the breakpoint. Also, in this screenshot, I started the debugging process with “gdb run”. Then, I used “gdb stepi” to step through the program one line at a time. Next, I began to examine the memory. At first, I copied the command verbatim from the ARM Assembly programming document, but I realized that I needed to use the memory address of where the breakpoint was inserted.

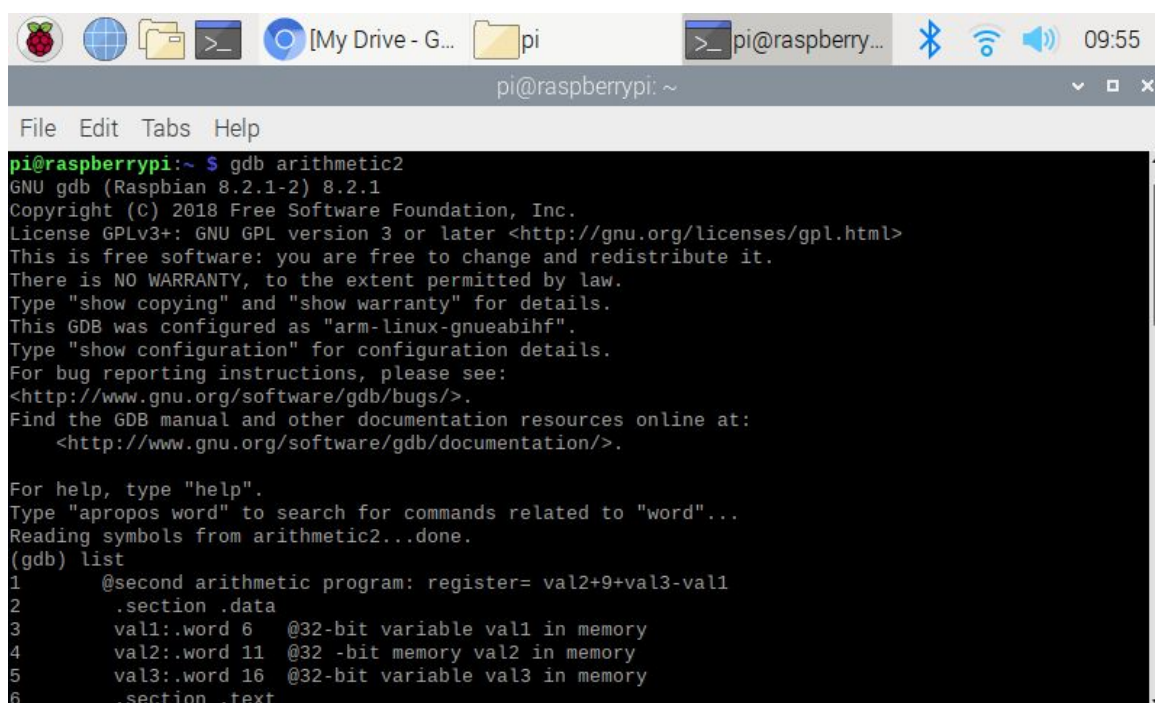


```

pi@raspberrypi: ~
File Edit Tabs Help
The program being debugged has been started already.
Start it from the beginning? (y or n) n
Program not restarted.
(gdb) info registers
r0             0x0             0
r1             0x7             7
r2             0x200ac         131244
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             0x1008c         0x1008c <_start+24>
cpsr           0x10           16
fpscr          0x0             0
(gdb) quit
A debugging session is active.

```

In this screenshot, I used “gdb info registers” to examine the registers. In r1, 7 is there because 2(r1) and 5(r2) are added together and stored in r1. In r2, the memory address of c is loaded there.



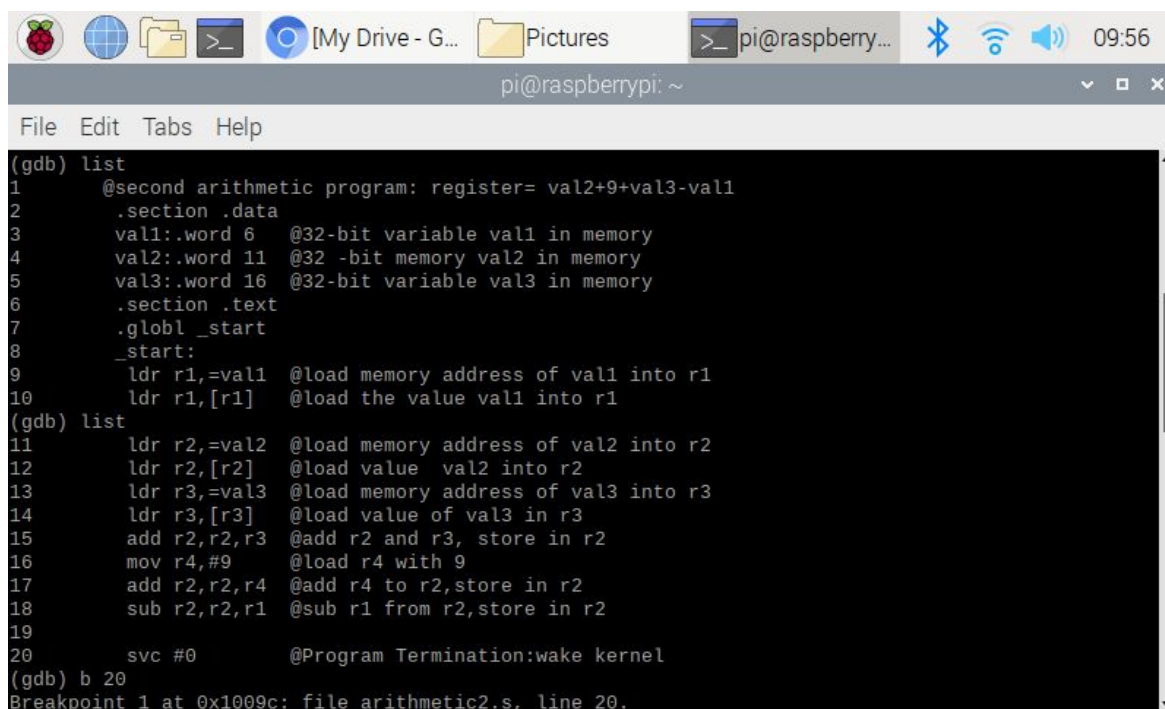
```

pi@raspberrypi: ~
File Edit Tabs Help
pi@raspberrypi:~ $ gdb arithmetic2
GNU gdb (Raspbian 8.2.1-2) 8.2.1
Copyright (C) 2018 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "arm-linux-gnueabi".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from arithmetic2...done.
(gdb) list
1      @second arithmetic program: register= val2+9+val3-val1
2      .section .data
3      val1:.word 6      @32-bit variable val1 in memory
4      val2:.word 11     @32-bit memory val2 in memory
5      val3:.word 16     @32-bit variable val3 in memory
6      .section .text

```

This screenshot shows the launch of the debugger with “gdb arithmetic2”.

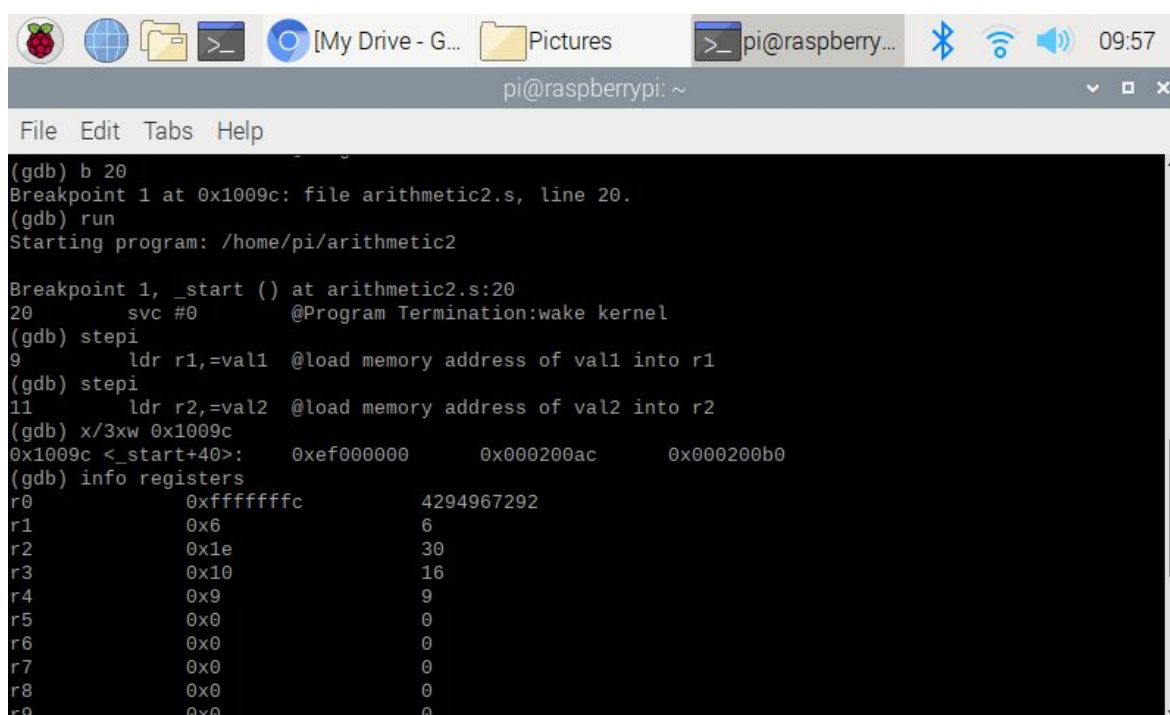


```

pi@raspberrypi: ~
File Edit Tabs Help
(gdb) list
1      @second arithmetic program: register= val2+9+val3-val1
2      .section .data
3      val1:.word 6      @32-bit variable val1 in memory
4      val2:.word 11     @32-bit memory val2 in memory
5      val3:.word 16     @32-bit variable val3 in memory
6      .section .text
7      .globl _start
8      _start:
9      ldr r1,=val1      @load memory address of val1 into r1
10     ldr r1,[r1]        @load the value val1 into r1
(gdb) list
11     ldr r2,=val2      @load memory address of val2 into r2
12     ldr r2,[r2]        @load value val2 into r2
13     ldr r3,=val3      @load memory address of val3 into r3
14     ldr r3,[r3]        @load value of val3 in r3
15     add r2,r2,r3       @add r2 and r3, store in r2
16     mov r4,#9          @load r4 with 9
17     add r2,r2,r4       @add r4 to r2,store in r2
18     sub r2,r2,r1       @sub r1 from r2,store in r2
19
20     svc #0             @Program Termination:wake kernel
(gdb) b 20
Breakpoint 1 at 0x1009c: file arithmetic2.s, line 20.

```

In this screenshot, I listed the first ten lines of code with “gdb list”, and I listed the next ten lines of code by repeating that same command.



```

pi@raspberrypi: ~
File Edit Tabs Help
(gdb) b 20
Breakpoint 1 at 0x1009c: file arithmetic2.s, line 20.
(gdb) run
Starting program: /home/pi/arithmetic2

Breakpoint 1, _start () at arithmetic2.s:20
20     svc #0             @Program Termination:wake kernel
(gdb) stepi
9      ldr r1,=val1      @load memory address of val1 into r1
(gdb) stepi
11     ldr r2,=val2      @load memory address of val2 into r2
(gdb) x/3xw 0x1009c
0x1009c <_start+40>:  0xef000000      0x000200ac      0x000200b0
(gdb) info registers
r0      0xffffffff      4294967292
r1      0x6              6
r2      0x1e             30
r3      0x10             16
r4      0x9              9
r5      0x0              0
r6      0x0              0
r7      0x0              0
r8      0x0              0
r9      0x0              0

```

In this screenshot, I set the breakpoint at line 20, and the memory address at which I placed the breakpoint appears “0X1009c”. Also, I ran the debugger, and then I used the “gdb stepi” to step through the program twice. Then, I used “gdb x/3xw 0x1009c” to examine the memory. Then

three memory addresses appeared, which is where I assume the val1, val2, and val3 memory addresses are located.

```

11      ldr r2,=val2 @load memory address of val2 into r2
(gdb) x/3xw 0x1009c
0x1009c <_start+40>:  0xef000000    0x000200ac    0x000200b0
(gdb) info registers
r0             0xffffffff    4294967292
r1             0x6           6
r2             0x1e          30
r3             0x10          16
r4             0x9           9
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             0x100a4       0x100a4 <_start+48>
cpsr           0x10          16
fpscr          0x0           0
(gdb) quit
A debugging session is active.

```

In this screenshot, I used “gdb info registers” to access the registers. In r1, there is a 6 because I loaded the value 6 here. In r2, there is a 30 because I added 11(r2) and 16(r3), and I also added 9 to r2, which is 36. Then, I subtracted 6(r1) from 36(r2), which is 30 and in hex 30 is 1e. In r3, there is a 16 because I loaded the value 16 there. In r4, I used mov to load 9 here.



### **Parallel Programming Skills Foundation: Arteen Ghafourikia**

#### **→ Identifying the components of the raspberry PI B+.**

The components are a single board computer with a Quad-core Multicore CPU with two USB ports, an ethernet controller, ethernet port, one GB RAM, camera port, two power ports, HDMI and the display ports.

#### **→ How many cores does the Raspberry Pi's B+ CPU have?**

- The Raspberry Pi B+ CPU has four cores, which is also known as a quad-core.

#### **→ List three main differences between X86 (CISC) and ARM Raspberry PI (RISC). Justify your answer and use your own words.**

- One of the differences between the ARM and INTEL processor is the instruction set. Intel has a CISC (Complex Instruction Set Computing) processor which allows for more versatile and detail oriented instructions to access memory while ARM has more registers.
- ARM is a RISC (Reduced Instruction Set Computing) processor giving it a more simple instruction set which provides ARM more speed allowing instructions to be executed faster; however, it is more difficult to program efficiently.
- Another notable difference is that ARM uses a BI-endian format after version 3, while Intel x86 still uses the little-endian format.

#### **→ What is the difference between sequential and parallel computation and identify the practical significance of each?**

- Sequential computation is executed on a single processor, and only one instruction can be executed at a time. At the same time, parallel computing is broken down into a series of instructions where each part executes simultaneously on different processors. Parallel computing is more efficient as you can solve bigger problems faster, while you would use sequential computation when only using one thread.

#### **→ Identify the basic form of data and task parallelism in computational problems.**

- Data parallelism is when you perform the same computation to numerous data items where the data will be divided and computed by different processors
- Task parallelism is when there are tasks that have to be done differently, and you give each task to a different process. The process will then be executed according to the given task and not the data.

#### **→ Explain the differences between processes and threads.**

- A process is the outline of a functioning program; they do not share the memory with other processes, While a thread is a process that can be broken into smaller parts and run individually. Threads also share the memory with the process they are in.

#### **→ What is OpenMP and what is OpenMP pragmas?**

- OpenMP is a library for parallel programming where it takes parts of the code and runs them parallel to the program.
- OpenMP pragmas are the compilers that oversee how the program functions and makes sure the program doesn't run into any problems.

#### **→ What applications benefit from multi-core (list four)?**

- Compilers
- Scientific applications

- Web Servers
- Multimedia applications

→ **Why Multicore? (why not single core, list four)**

- Multicore is faster
- Computer architecture favors parallelism
- Single core has difficult design while Multicore has multiple processes making it more versatile
- Single core can overheat



## Parallel Programming Basics: Arteen Ghafourikia

```
pi@raspberrypi:~ $ nano spmd2.c
Use "fg" to return to nano.

[1]+  Stopped                  nano spmd2.c
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
pi@raspberrypi:~ $ ./spmd2 4

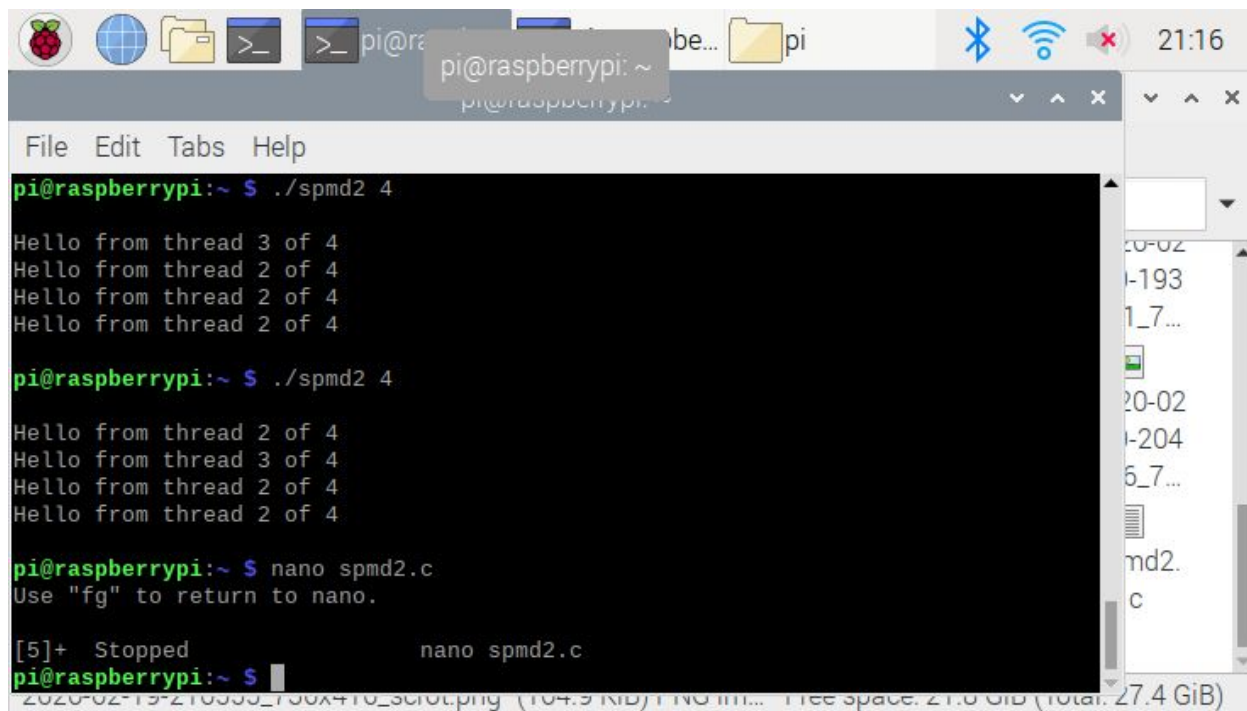
Hello from thread 3 of 4
Hello from thread 2 of 4
Hello from thread 2 of 4
Hello from thread 2 of 4

pi@raspberrypi:~ $ ./spmd2 3

Hello from thread 2 of 3
Hello from thread 0 of 3
Hello from thread 0 of 3

pi@raspberrypi:~ $
```

In this screenshot, I ran the C program that was given using `./spmd2` four and realized that the thread ids are all the same. I then alternated the number of threads, but still had threads that had the same id.



The screenshot shows a terminal window on a Raspberry Pi. The window title is "pi@raspberrypi: ~". The terminal output shows the execution of a program named "spmd2" with 4 threads. The output is as follows:

```
pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 3 of 4
Hello from thread 2 of 4
Hello from thread 2 of 4
Hello from thread 2 of 4

pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 2 of 4
Hello from thread 3 of 4
Hello from thread 2 of 4
Hello from thread 2 of 4

pi@raspberrypi:~ $ nano spmd2.c
Use "fg" to return to nano.

[5]+ Stopped nano spmd2.c
pi@raspberrypi:~ $
```

The terminal window also shows a file explorer on the right side, displaying a list of files and folders, including "spmd2.c".

In this screenshot, I ran the program a couple more times to see if the thread ids would always be the same, and it turned out to be true.

```

pi@raspberrypi: ~
File Edit Tabs Help
Use "fg" to return to nano.

[11]+ Stopped nano spmd2.c
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
pi@raspberrypi:~ $ ./spmd2 4

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

pi@raspberrypi:~ $ ./spmd2 4

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

pi@raspberrypi:~ $

```

In this screenshot, I ran the program after I updated the code by declaring the variable within the block, so each thread keeps track of their id. The problem with the code was that it was only initializing the variable outside the block of code, causing the threads to share that variable's memory location. However, after I made the changes, the thread id displayed different values.

```

GNU nano 3.2 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();

```

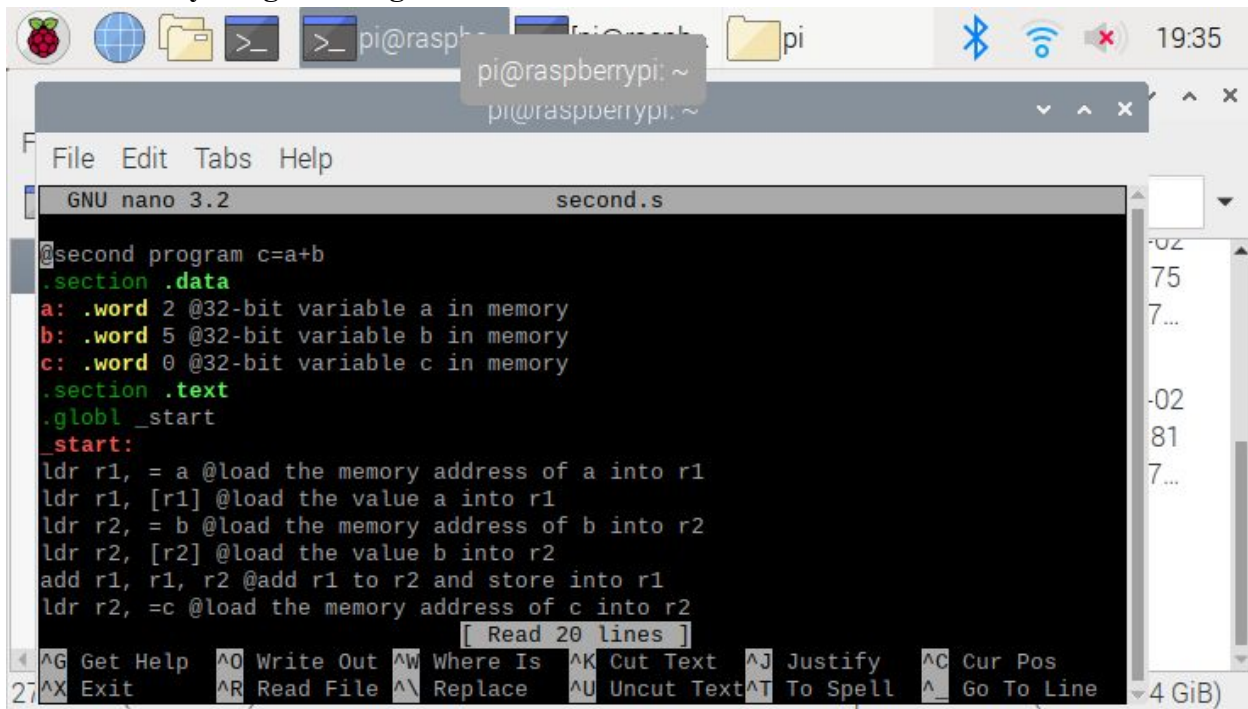
```

pi@ras:~$ nano spmd2.c
GNU nano 3.2 spmd2.c
pi@ras:~$
\pi@ras:~$
pi@ras:~$ if(argc>1){
pi@ras:~$ omp_set_num_threads(atoi(argv[1]));
pi@ras:~$ }
pi@ras:~$
pi@ras:~$ #pragma omp parallel
pi@ras:~$ {
pi@ras:~$     int id=omp_get_thread_num();
pi@ras:~$     int numThreads = omp_get_num_threads();
pi@ras:~$     printf("Hello from thread %d of %d\n",id,numThreads);
pi@ras:~$ }
pi@ras:~$
pi@ras:~$ printf("\n");
pi@ras:~$ return 0;
pi@ras:~$
^G Get Help  ^O Write Out  ^W Where Is  ^K Cut Text  ^J Justify  ^C Cur Pos
^X Exit      ^R Read File  ^\ Replace   ^U Uncut Text ^T To Spell  ^_ Go To Line
2020-02-15 21:05:50 raspberrypi-32bit.png (104.5 KiB) / NO m... Free Space: 21.6 GiB (total: 27.4 GiB)

```

These two screenshots show the correct version of the code. The only difference between the correct version of the code and the old version is that the new version initializes a new variable giving us different thread ids. In contrast, the older one uses the same variable, sharing that variable's memory.

## Arm Assembly Programming:Arteen Ghafourikia



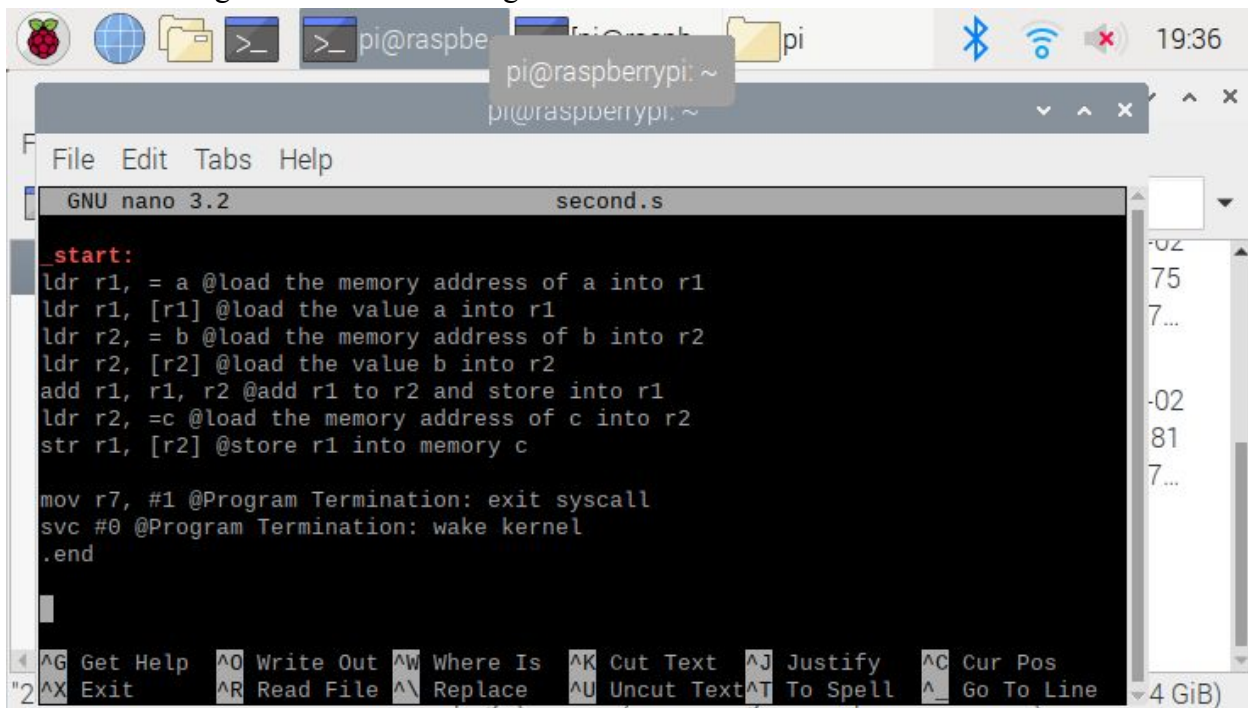
The screenshot shows the GNU nano 3.2 text editor with the file 'second.s' open. The code defines two variables, 'a' and 'b', in the data section and then performs operations in the text section. The text section starts with a global symbol '\_start' and includes instructions to load memory addresses and values into registers r1 and r2, and to add the values.

```

@second program c=a+b
.section .data
a: .word 2 @32-bit variable a in memory
b: .word 5 @32-bit variable b in memory
c: .word 0 @32-bit variable c in memory
.section .text
.globl _start
_start:
ldr r1, = a @load the memory address of a into r1
ldr r1, [r1] @load the value a into r1
ldr r2, = b @load the memory address of b into r2
ldr r2, [r2] @load the value b into r2
add r1, r1, r2 @add r1 to r2 and store into r1
ldr r2, =c @load the memory address of c into r2

```

In this screenshot, I am showing the example code. In this code, we are loading the memory addresses into registers and then loading the value into them



The screenshot shows the continuation of the ARM assembly program in the GNU nano 3.2 editor. It includes instructions to add the values in r1 and r2, load the memory address of 'c' into r2, and store the value in r1 into memory at the address in r2. The program then terminates using a syscall.

```

mov r7, #1 @Program Termination: exit syscall
svc #0 @Program Termination: wake kernel
.end

```

This screenshot is displaying the rest of the code.



```

pi@raspberrypi: ~
pi@raspberrypi: ~
pi@raspberrypi: ~
pi@raspberrypi: ~
File Edit Tabs Help
<http://www.gnu.org/software/gdb/documentation/>.
For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from second...done.
(gdb) list
1      @second program c=a+b
2      .section .data
3      a: .word 2 @32-bit variable a in memory
4      b: .word 5 @32-bit variable b in memory
5      c: .word 0 @32-bit variable c in memory
6      .section .text
7      .globl _start
8      _start:
9      ldr r1, = a @load the memory address of a into r1
10     ldr r1, [r1] @load the value a into r1
(gdb) b 15
Breakpoint 1 at 0x1008c: file second.s, line 15.
(gdb)

```

In this screenshot, I listed the first ten lines of code with (gdb) list, and then I placed a breakpoint at line 15.

```

pi@raspberrypi: ~
pi@raspberrypi: ~
pi@raspberrypi: ~
pi@raspberrypi: ~
File Edit Tabs Help
6      .section .text
7      .globl _start
8      _start:
9      ldr r1, = a @load the memory address of a into r1
10     ldr r1, [r1] @load the value a into r1
(gdb) b 15
Breakpoint 1 at 0x1008c: file second.s, line 15.
(gdb) run
Starting program: /home/pi/CSC3210-TheCommuters/second

Breakpoint 1, _start () at second.s:15
15     str r1, [r2] @store r1 into memory c
(gdb) stepi
17     mov r7, #1 @Program Termination: exit syscall
(gdb) x/3xw 0x1008
0x1008: Cannot access memory at address 0x1008
(gdb) x/3xw 0x1008c
0x1008c <_start+24>:      0xe5821000      0xe3a07001      0xef000000
(gdb)

```

In this screenshot, I ran the program and then stepped into the next line and then displayed 3 of the memory addresses.

```

(gdb) info registers
r0          0x0          0
r1          0x7          7
r2          0x200ac       131244
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          0x7efff6d0    0x7efff6d0
lr          0x0          0
pc          0x1008c       0x1008c <_start+24>
cpsr        0x10         16
fpscr       0x0          0

```

Here is a screenshot of the registers with the loaded values.

## Part 2:

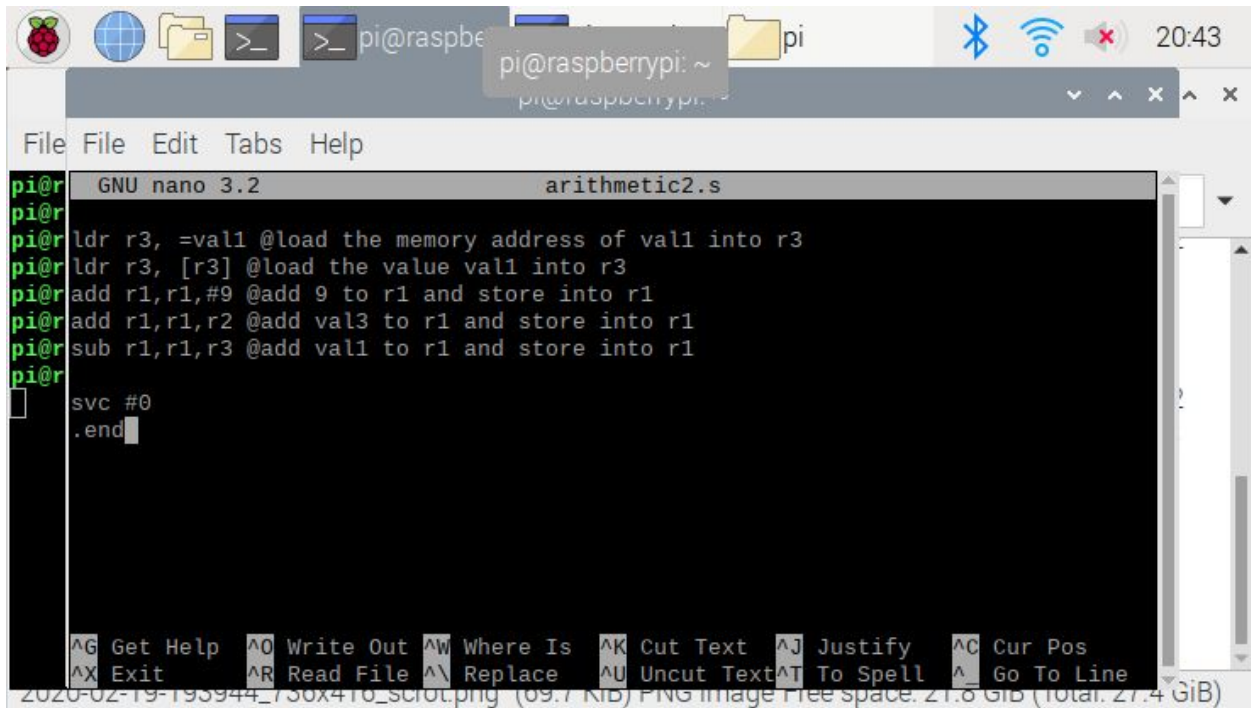
```

GNU nano 3.2 arithmetic2.s
@second program part 2
.section .data
val1:.word 6 @32 bit variable
val2:.word 11 @32 bit variable
val3:.word 16 @32 bit variable

.section .text
.globl _start
_start:
ldr r1, =val2 @load the memory address of val2 into r1
ldr r1,[r1] @load the value val2 into r1
ldr r2,=val3 @load the memory address of val3 into r2
ldr r2,[r2] @load the value val3 into r2
ldr r3, =val1 @load the memory address of val1 into r3

```

In this screenshot, I am displaying the code for the second part. In this program, I am loading the memory addresses into registers to which I then use the registers to perform some basic arithmetic. The value of r2 is going to be 16, and r3 will be 6 after the values are loaded into the registers.

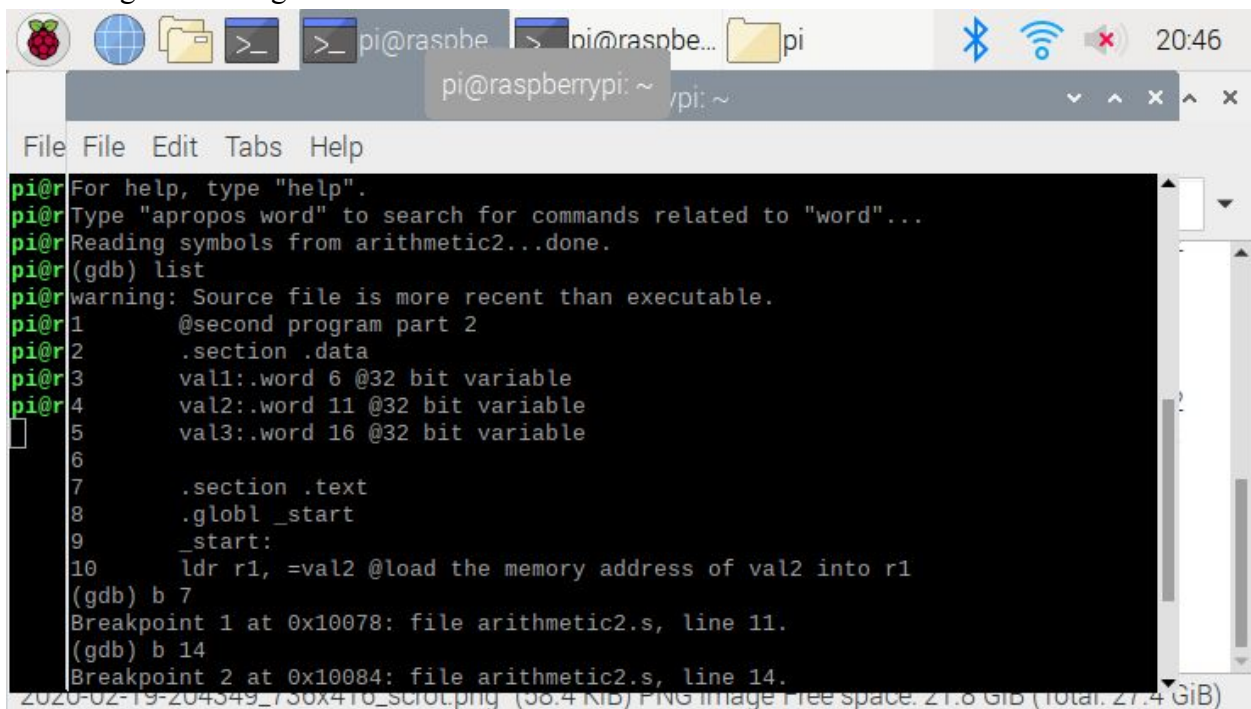


```

pi@raspberrypi: ~
File Edit Tabs Help
GNU nano 3.2 arithmetic2.s
pi@
pi@
pi@ ldr r3, =val1 @load the memory address of val1 into r3
pi@ ldr r3, [r3] @load the value val1 into r3
pi@ add r1,r1,#9 @add 9 to r1 and store into r1
pi@ add r1,r1,r2 @add val3 to r1 and store into r1
pi@ sub r1,r1,r3 @add val1 to r1 and store into r1
pi@
pi@ svc #0
pi@ .end
^G Get Help ^O Write Out ^W Where Is ^K Cut Text ^J Justify ^C Cur Pos
^X Exit ^R Read File ^N Replace ^U Uncut Text ^T To Spell ^_ Go To Line
2020-02-19-193944_736x416_scroll.png (69.7 KiB) PNG image Free space: 21.8 GiB (total: 27.4 GiB)

```

In this screenshot, I am showing the rest of the code for the second part. Here you can see that I am adding and storing the new values in r1.



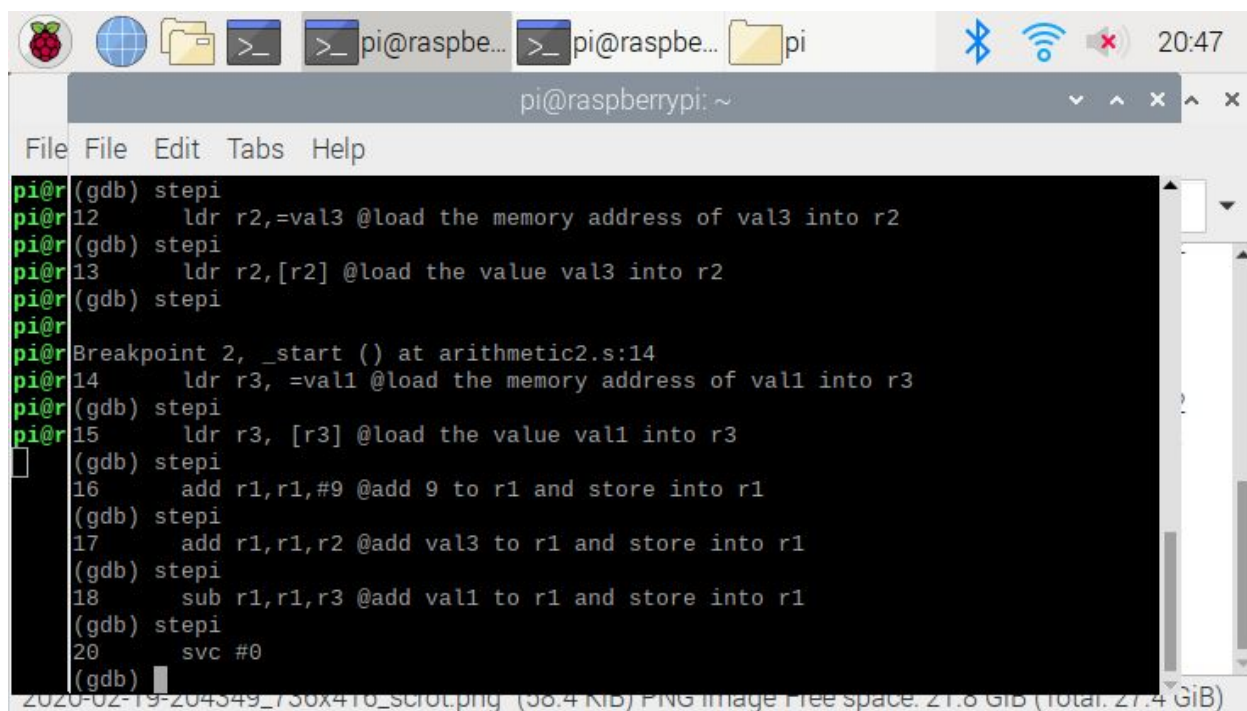
```

pi@raspberrypi: ~
File Edit Tabs Help
pi@
pi@ For help, type "help".
pi@ Type "apropos word" to search for commands related to "word"...
pi@ Reading symbols from arithmetic2...done.
pi@ (gdb) list
pi@ warning: Source file is more recent than executable.
pi@ 1      @second program part 2
pi@ 2      .section .data
pi@ 3      val1:.word 6 @32 bit variable
pi@ 4      val2:.word 11 @32 bit variable
pi@ 5      val3:.word 16 @32 bit variable
pi@ 6
pi@ 7      .section .text
pi@ 8      .globl _start
pi@ 9      _start:
pi@ 10     ldr r1, =val2 @load the memory address of val2 into r1
pi@ (gdb) b 7
pi@ Breakpoint 1 at 0x10078: file arithmetic2.s, line 11.
pi@ (gdb) b 14
pi@ Breakpoint 2 at 0x10084: file arithmetic2.s, line 14.
2020-02-19-204349_736x416_scroll.png (58.4 KiB) PNG image Free space: 21.8 GiB (total: 27.4 GiB)

```

In this screenshot, I listed the first ten lines of my program and then placed a breakpoint at 7 and 14.



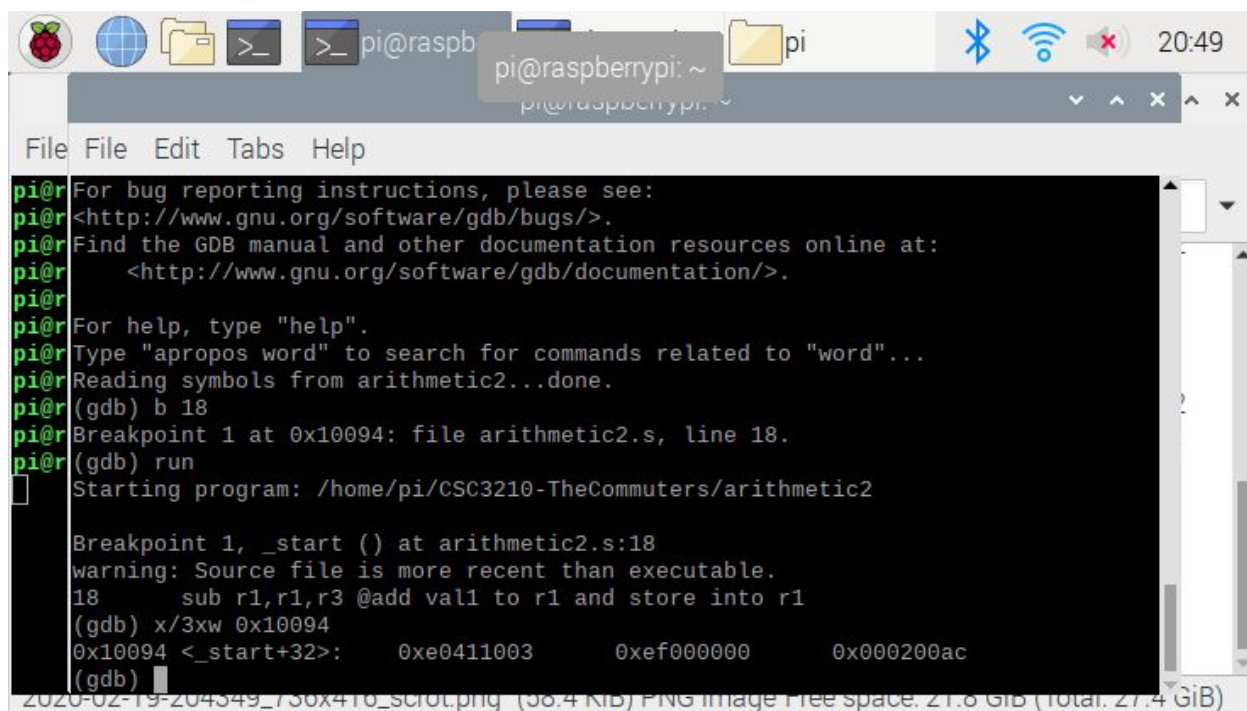


```

pi@raspberrypi: ~
File Edit Tabs Help
pi@ (gdb) stepi
pi@ 12    ldr r2,=val3 @load the memory address of val3 into r2
pi@ (gdb) stepi
pi@ 13    ldr r2,[r2] @load the value val3 into r2
pi@ (gdb) stepi
pi@
pi@ Breakpoint 2, _start () at arithmetic2.s:14
pi@ 14    ldr r3, =val1 @load the memory address of val1 into r3
pi@ (gdb) stepi
pi@ 15    ldr r3, [r3] @load the value val1 into r3
pi@ (gdb) stepi
pi@ 16    add r1,r1,#9 @add 9 to r1 and store into r1
pi@ (gdb) stepi
pi@ 17    add r1,r1,r2 @add val3 to r1 and store into r1
pi@ (gdb) stepi
pi@ 18    sub r1,r1,r3 @add val1 to r1 and store into r1
pi@ (gdb) stepi
pi@ 20    svc #0
pi@ (gdb)

```

In this screenshot, I was stepping into each line of code to see what I would see, and it showed each line.



```

pi@raspberrypi: ~
File Edit Tabs Help
pi@ For bug reporting instructions, please see:
pi@ <http://www.gnu.org/software/gdb/bugs/>.
pi@ Find the GDB manual and other documentation resources online at:
pi@ <http://www.gnu.org/software/gdb/documentation/>.
pi@
pi@ For help, type "help".
pi@ Type "apropos word" to search for commands related to "word"...
pi@ Reading symbols from arithmetic2...done.
pi@ (gdb) b 18
pi@ Breakpoint 1 at 0x10094: file arithmetic2.s, line 18.
pi@ (gdb) run
pi@ Starting program: /home/pi/CSC3210-TheCommuters/arithmetic2

Breakpoint 1, _start () at arithmetic2.s:18
warning: Source file is more recent than executable.
18    sub r1,r1,r3 @add val1 to r1 and store into r1
(gdb) x/3xw 0x10094
0x10094 <_start+32>:    0xe0411003    0xef000000    0x000200ac
(gdb)

```

In this screenshot, I placed a breakpoint at line 18 and then ran the program. I then displayed the registers to see what I would get, and it displayed three memory addresses, which are 0xe0411003, 0xef000000, and 0x000200ac.

```

pi@r pc          0x10094          0x10094 <_start+32>
pi@r cpsr         0x10            16
pi@r fpscr        0x0             0
pi@r (gdb) stepi
pi@r 20          svc #0
pi@r (gdb) info register
pi@r r0          0x0              0
pi@r r1          0x1e             30
pi@r r2          0x10             16
pi@r r3          0x6               6
pi@r r4          0x0              0
pi@r r5          0x0              0
pi@r r6          0x0              0
pi@r r7          0x0              0
pi@r r8          0x0              0
pi@r r9          0x0              0
pi@r r10         0x0              0
pi@r r11         0x0              0
pi@r r12         0x0              0

```

In this screenshot, I displayed the registers using (gdb) info register, and as you can see, the result in register 1 is 30d(1E), which would be the current value if you compute the given arithmetic( $11+9+16-6=30$ ).

```

pi@r r0          0x0              0
pi@r r1          0x1e             30
pi@r r2          0x10             16
pi@r r3          0x6               6
pi@r r4          0x0              0
pi@r r5          0x0              0
pi@r r6          0x0              0
pi@r r7          0x0              0
pi@r r8          0x0              0
pi@r r9          0x0              0
pi@r r10         0x0              0
pi@r r11         0x0              0
pi@r r12         0x0              0
pi@r sp          0x7efff6c0       0x7efff6c0
pi@r lr          0x0              0
pi@r pc          0x10098          0x10098 <_start+36>
pi@r cpsr         0x10            16
pi@r fpscr        0x0             0
pi@r (gdb)

```

This is a screenshot of the rest of the registers.

### **Parallel Programming Skills Foundation: Joan Galicia**

#### **→ Identifying the components of the raspberry PI B+.**

- ◆ The Raspberry Pi's components are a single board computer, quad -core multicore CPU, 1 GB RAM, 2 Usb ports, ethernet/ controller, Power port, Camera, HDMI, Power, and Display.

#### **→ How many cores does the Raspberry Pi's B+ CPU have?**

- ◆ .The RSP B+ has 4 cores in its CPU as it is denoted by having quad-core

#### **→ List three main differences between X86 (CISC) and ARM Raspberry PI (RISC). Justify your answer and use your own words.**

- ◆ The major difference between x86 and ARM is that they have different languages. This means that if an instruction set was given and made to the x86, it could not be used for the ARM.
- ◆ Another key difference is their difference in processing power. The x86 was designed to handle larger and complex instructions while ARM was designed to be fast. Arm's memory is based on loading and storing as its instruction sets can only be used in registers.
- ◆ X86 is focused on efficiency while ARM has its focus on fast execution for less clock cycles per instruction

#### **→ What is the difference between sequential and parallel computation and identify the practical significance of each?**

- ◆ In sequential computation a task is runned through a processor and completed one by one. Its Purpose is to run similar tasks that are completed at similar times. The set back is that it takes more time to complete the tasks because only one processor is being utilized.
- ◆ Parallel computation is a way for multiple tasks to be completed. It is an efficient method because it uses multiple processors that break down tasks into a series of instructions and they run at the same time.

#### **→ Identify the basic form of data and task parallelism in computational problems.**

- ◆ Data Parallelism is where the same type of data is split among the processors and each of the processors are doing the same calculations with their own piece of data. An example of this, where you are given an image and you want to know how many pixels there are. This would mean that the process needed to count the number of pixels would be the same and you would just need to count every individual pixel.
- ◆ Task Parallelism is where multiple tasks are needed to be executed and they have different functions. This parallelism is based on the task itself and not solely on the data within the task. An example of this, is where you have an array with some amount of integers and you would like to find the minimum, maximum, and average of this array. In this case we are looking at the same data but to get these results you would need different processors to look at the data and compute it.

→ **Explain the differences between processes and threads.**

- ◆ Both processes and threads are part of the execution of a program that run through the memory, but the differences will be given below:
- ◆ Processes run in their own memory space and are given everything they need to execute a program even having one thread of execution. The way threads are different is that it's an entity within a process which is scheduled to be executed, but it has to be in the same memory space.

→ **What is OpenMP and what is OpenMP pragmas?**

- ◆ OpenMP is a library that uses a thread pool pattern of simultaneous execution controls that supports shared memory and data multiprocessing.
- ◆ OpenMP pragmas is an implicit multithreading compiler where the library will control thread creation. It is a low level compiler that helps programmers become less error prone.

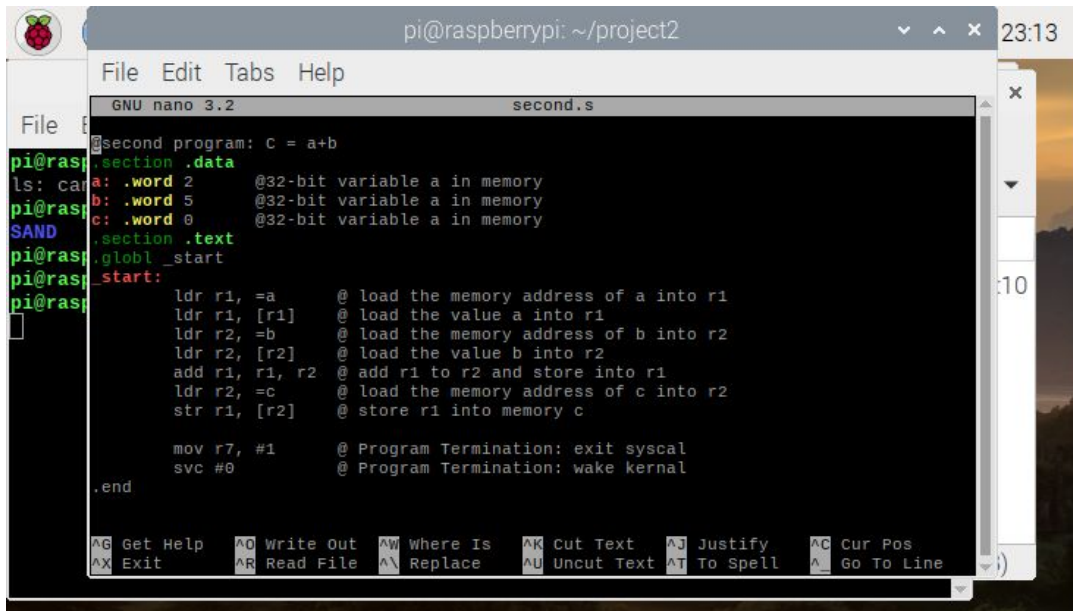
→ **What applications benefit from multi-core (list four)?**

- ◆ Compilers
- ◆ Scientific applications
- ◆ Web servers
- ◆ Any applications with thread level parallelism

→ **Why Multicore? (why not single core, list four)**

- ◆ Multiple single process executions
- ◆ Increased inputs of system
- ◆ Faster execution
- ◆ Power consumption problem is reduced allowing for an increased frequency scaling

## Parallel Programming Basics: Joan Galicia



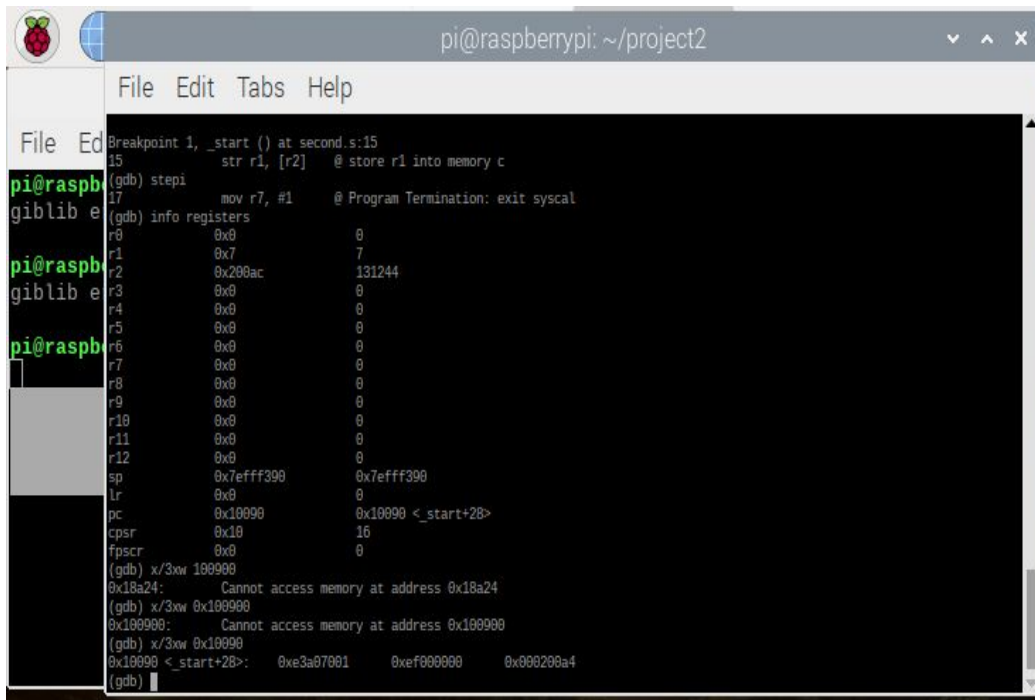
```

pi@raspberrypi: ~/project2
File Edit Tabs Help
GNU nano 3.2 second.s
second program: c = a+b
.section .data
a: .word 2 @32-bit variable a in memory
b: .word 5 @32-bit variable a in memory
c: .word 0 @32-bit variable a in memory
.section .text
.globl _start
_start:
    ldr r1, =a @ load the memory address of a into r1
    ldr r1, [r1] @ load the value a into r1
    ldr r2, =b @ load the memory address of b into r2
    ldr r2, [r2] @ load the value b into r2
    add r1, r1, r2 @ add r1 to r2 and store into r1
    ldr r2, =c @ load the memory address of c into r2
    str r1, [r2] @ store r1 into memory c

    mov r7, #1 @ Program Termination: exit syscall
    svc #0 @ Program Termination: wake kernal
.end

AG Get Help AD Write Out AW Where Is AK Cut Text AJ Justify AC Cur Pos
AX Exit AR Read File AN Replace AU Uncut Text AT To Spell A Go To Line
  
```

In this screenshot is the code written for second.s in the next screen shot is where the code is debugged. The only difference in this program is the way variables are used and called for. This language uses first assigns the memory address to the register and then uses load instead of move to assign the variables into a register.

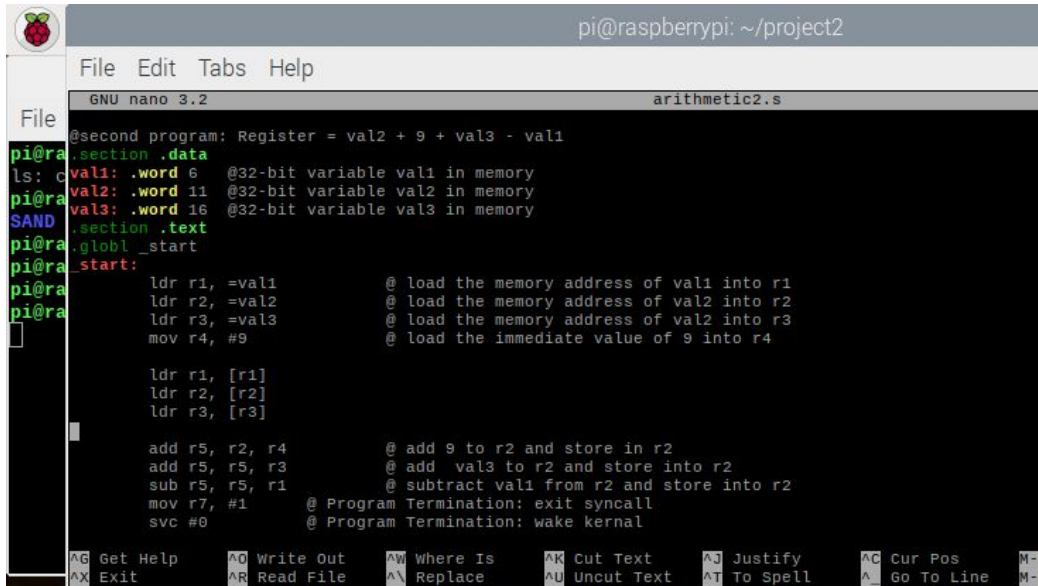


```

pi@raspberrypi: ~/project2
File Edit Tabs Help
Breakpoint 1, _start () at second.s:15
15      str r1, [r2] @ store r1 into memory c
(gdb) stepi
17      mov r7, #1 @ Program Termination: exit syscall
(gdb) info registers
r0          0x0          0
r1          0x7          7
r2          0x200ac      131244
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          0x7efff390   0x7efff390
lr          0x0          0
pc          0x10090      0x10090 <_start+28>
cpsr       0x10         16
fpscr      0x0          0
(gdb) x/3mw 100900
0x18a24: Cannot access memory at address 0x18a24
(gdb) x/3mw 0x100900
0x100900: Cannot access memory at address 0x100900
(gdb) x/3mw 0x10090
0x10090 <_start+28>: 0xe3a07001 0xef000000 0x000000a4
(gdb)
  
```

At breakpoint 15 the memory address resulted in 0x01008 and once “stepi” was commanded it then proceeded to the next line where the code is. This screenshot is set up at line 17 and so the

memory registers gave this address 0x10090. After accessing this address it gave 3 more addresses that when trying to access, did not execute.



```

pi@raspberrypi: ~/project2
File Edit Tabs Help
GNU nano 3.2 arithmetic2.s
@second program: Register = val2 + 9 + val3 - val1
.section .data
val1: .word 6 @32-bit variable val1 in memory
val2: .word 11 @32-bit variable val2 in memory
val3: .word 16 @32-bit variable val3 in memory
.section .text
.globl _start
_start:
    ldr r1, =val1 @ load the memory address of val1 into r1
    ldr r2, =val2 @ load the memory address of val2 into r2
    ldr r3, =val3 @ load the memory address of val2 into r3
    mov r4, #9 @ load the immediate value of 9 into r4

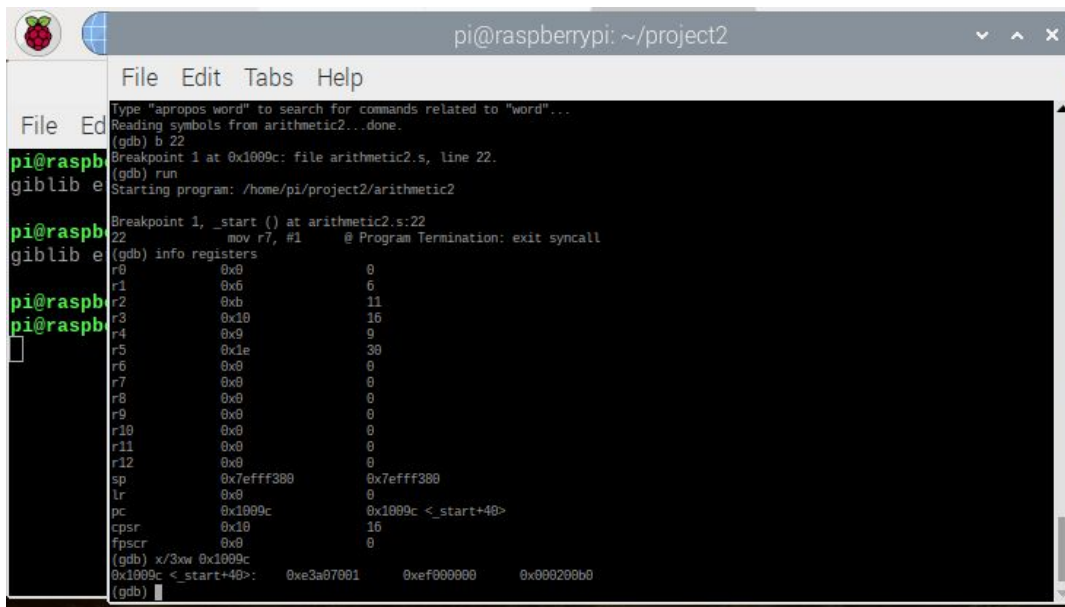
    ldr r1, [r1]
    ldr r2, [r2]
    ldr r3, [r3]

    add r5, r2, r4 @ add 9 to r2 and store in r2
    add r5, r5, r3 @ add val3 to r2 and store into r2
    sub r5, r5, r1 @ subtract val1 from r2 and store into r2
    mov r7, #1 @ Program Termination: exit syncall
    svc #0 @ Program Termination: wake kernal

^G Get Help ^O Write Out ^W Where Is ^K Cut Text ^J Justify ^C Cur Pos ^M-L
^X Exit ^R Read File ^\ Replace ^U Uncut Text ^T To Spell ^_ Go To Line ^M-E

```

This screenshot is the code used for arithmetic2. From the past program, second, I learned to use ldr to load the memory addresses of my variables to the registers. This program was asking to add three values and subtract one value.



```

pi@raspberrypi: ~/project2
File Edit Tabs Help
Type "apropos word" to search for commands related to "word"...
Reading symbols from arithmetic2...done.
(gdb) b 22
Breakpoint 1 at 0x1009c: file arithmetic2.s, line 22.
(gdb) run
Starting program: /home/pi/project2/arithmetic2

Breakpoint 1, _start () at arithmetic2.s:22
22      mov r7, #1 @ Program Termination: exit syncall
(gdb) info registers
r0      0x0      0
r1      0x6      6
r2      0xb      11
r3      0x10     16
r4      0x9      9
r5      0x1e     30
r6      0x0      0
r7      0x0      0
r8      0x0      0
r9      0x0      0
r10     0x0      0
r11     0x0      0
r12     0x0      0
sp      0x7efff380 0x7efff380
lr      0x0      0
pc      0x1009c 0x1009c <_start+40>
cpsr    0x10     16
fpscr   0x0      0
(gdb) x/3xw 0x1009c
0x1009c <_start+40>: 0xe3a07001 0xef000000 0x000200b0
(gdb)

```

The image above is arithmetic2 debugged. The values given and are shown in registers r1, r2, r3, and r4. The result  $(11+9+16-6)$  is located in register r5 which is 30 in decimal and in Hexadecimal the answer is 1E. I also accessed the memory access (seen in register pc) where it would give me three more addresses.

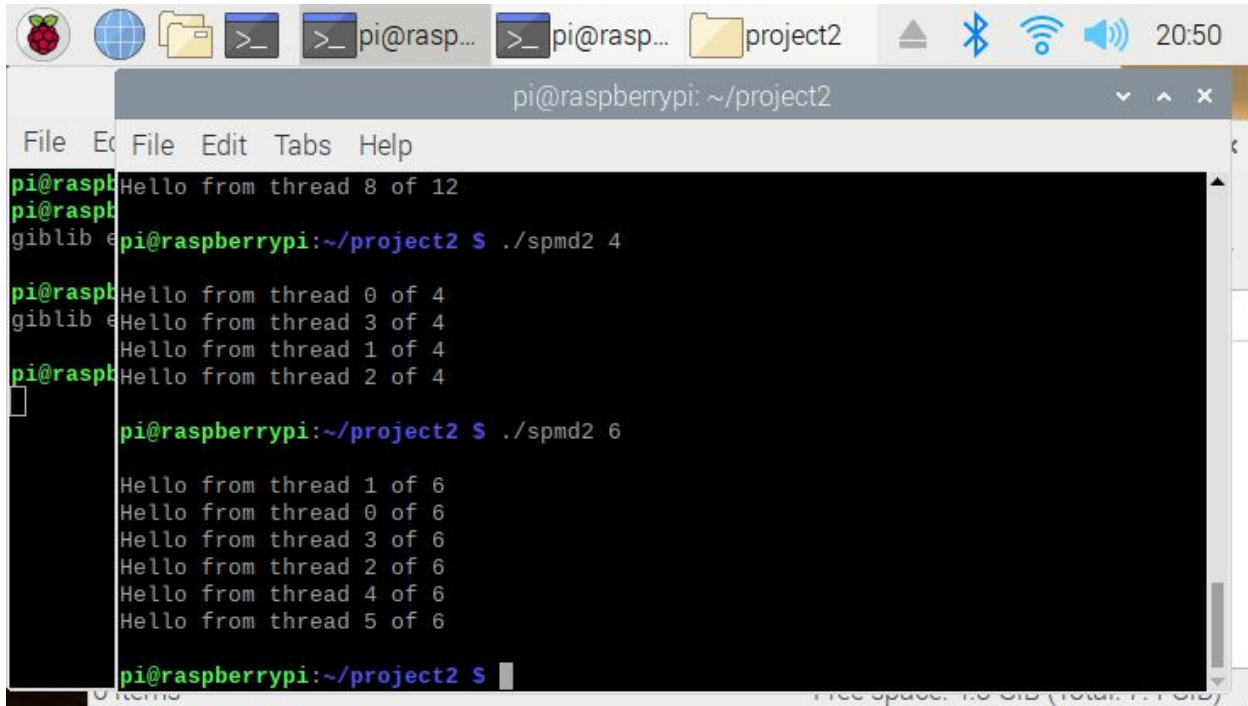


```

pi@raspberrypi: ~/project2
File Edit Tabs Help
GNU nano 3.2 spmd2.c Modified
//Joan
#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;
}
^G Get Help ^O Write Out ^W Where Is ^K Cut Text ^J Justify ^C Cur Pos
^X Exit ^R Read File ^\ Replace ^U Uncut Text ^T To Spell ^_ Go To Line

```

This screenshot is displaying the code for a new program I have started working on, called spmd2.c. This program is different because it is written in the C Language, and is used to show how parallel programming works. The errors that I came across from this program was when I tried to compile the program into an executable as there were only simple errors being indicated.



```
pi@raspb... pi@raspb... project2 20:50
pi@raspberrypi: ~/project2
File Edit Tabs Help
pi@raspberrypi:~/project2 $ ./spmd2 4
Hello from thread 8 of 12
pi@raspberrypi:~/project2 $ ./spmd2 6
Hello from thread 0 of 4
Hello from thread 3 of 4
Hello from thread 1 of 4
Hello from thread 2 of 4
pi@raspberrypi:~/project2 $ ./spmd2 6
Hello from thread 1 of 6
Hello from thread 0 of 6
Hello from thread 3 of 6
Hello from thread 2 of 6
Hello from thread 4 of 6
Hello from thread 5 of 6
pi@raspberrypi:~/project2 $
```

In this last screen show the output of the `spmd2.c` program is displayed. Before I was able to obtain this output, the program `spmd2.c` had to be compiled. I compiled the program using the GNU Compiler Collection where it created an executable program that the computer can use. The displays n number of lines based on the number given when executing the program.



### **Parallel Programming Skills Foundation: Andre Nguyenphuc**

#### **→ Identifying the components on the Raspberry PI B+**

- ◆ Display port, Power port, CPU/RAM, HDMI port, Camera port, Second power port, Ethernet port, Ethernet controller, 2 USB ports, Quad-core CPU

#### **→ How many cores does the Raspberry Pi's B+ CPU have**

- ◆ Quad-Core Multicore (4)

#### **→ List three main differences between the X86 (CISC) and ARM Raspberry PI (RISC). Justify your answer and use your own words**

- ◆ One main difference between X86 and ARM is the instruction set. X86 has a larger and has more features in the instruction which allows it to have more operations and addressing modes. ARM has a more simplified instruction set which allows it to have more general purpose registers than X86.
- ◆ ARM is also able to use instructions that operate only on registers and uses a Load/Store memory model for memory access. X86 is able to use different and more complex instructions to access memory.
- ◆ Another difference between X86 and ARM is that X86 uses the little-endian format while ARM uses BI-endian and includes a setting that allows for switchable endianness.

#### **→ What is the difference between sequential and parallel computation and identify the practical significance of each?**

- ◆ Sequential computation is done on a single processor and breaks down a problem into a series of instructions and each instruction can only be executed one at a time. Sequential computation costs less than parallel computation due to it only being done on a single processor, but will take longer than parallel computation.
- ◆ Parallel computation is done on multiple processors and breaks down a problem into separate parts that can be solved concurrently, and each part can then be further broken down to a series of instructions. Parallel computation is faster than sequential computation and load on the processors is not high because one processor is not doing the whole task.

#### **→ Identify the basic form of data and task parallelism in computational problems**

- ◆ Data parallelism is dividing up data and doing the same work on different processors. An example that represents data parallelism is an assembly line because there are multiple people doing the same tasks.
- ◆ Task parallelism is dividing up tasks to different processors. An example of task parallelism would be any group project where team members will have tasks divided to them to complete on their own.

#### **→ Explain the differences between processes and threads**

- ◆ A process is the abstraction of a running program while a thread is a lightweight process that allows a single executable/process to be decomposed to smaller,

independent parts. A difference includes processes do not share memory with each other while threads all share a common memory of the process they belong to.

→ **What is OpenMP and what is OpenMP pragmas?**

- ◆ OpenMP is a library for parallel programming and all the threads share memory and data
- ◆ OpenMP pragmas are compiler directives that enable the compiler to generate threaded code

→ **What applications benefit from multi-core (list four)?**

- ◆ Database servers
- ◆ Web servers
- ◆ Compilers
- ◆ Multimedia applications

→ **Why Multicore? (why not single core, list four)**

- ◆ Many new applications are multithreaded so they need multi-core processors to run
- ◆ Single-core processors' clocks frequencies are difficult to make even higher
- ◆ Multi-core processors have faster execution than single-core due to parts of problems being solved concurrently
- ◆ Uses less power than single-core

**Parallel Programming Basics: Andre Nguyenphuc**

```

pi@raspberrypi: ~
File Edit Tabs Help
pi@raspberrypi:~ $ nano spmd2.c
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
pi@raspberrypi:~ $ ./spmd2 4

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

pi@raspberrypi:~ $ ./spmd2 4

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

pi@raspberrypi:~ $ ./spmd 5
bash: ./spmd: No such file or directory
pi@raspberrypi:~ $ ./spmd2 5

```

In this screenshot I compiled the spmd2 program then tested it with 4 which means how many threads to fork. This showed me that the order of the threads is out of order.

```

pi@raspberrypi: ~
File Edit Tabs Help
pi@raspberrypi:~ $ ./spmd2 5
Hello from thread 2 of 5
Hello from thread 1 of 5
Hello from thread 3 of 5
Hello from thread 0 of 5
Hello from thread 4 of 5

pi@raspberrypi:~ $ ./spmd2 8
Hello from thread 2 of 8
Hello from thread 1 of 8
Hello from thread 0 of 8
Hello from thread 3 of 8
Hello from thread 4 of 8
Hello from thread 7 of 8
Hello from thread 5 of 8
Hello from thread 6 of 8

```

I tested more threads here to see if I can go past 4 threads and the program allowed me and like the 4 threads the order for the threads seem to be out of order.

```

GNU nano 3.2      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);
}
^G Get Help  ^O Write Out ^W Where Is  ^K Cut Text  ^J Justify   ^C Cur Pos
^X Exit      ^R Read File ^\ Replace  ^U Uncut Text ^T To Spell  ^_ Go To Line

```

This is the C program which was something new for me. I observed that some commands were different from Java but mean the same thing like printf in java is system.out.print. I also had to make line 5 a comment and fix lines 12 and 13 to have id and numThreads be declared as variables.

```

GNU nano 3.2      spmd2.c

    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;
}

```

^G Get Help ^O Write Out ^W Where Is ^K Cut Text ^J Justify ^C Cur Pos  
^X Exit ^R Read File ^\ Replace ^U Uncut Text ^T To Spell ^\_ Go To Line

This is just the rest of the spmd2 code

### ARM Assembly Programming: Andre Nguyenphuc:

```

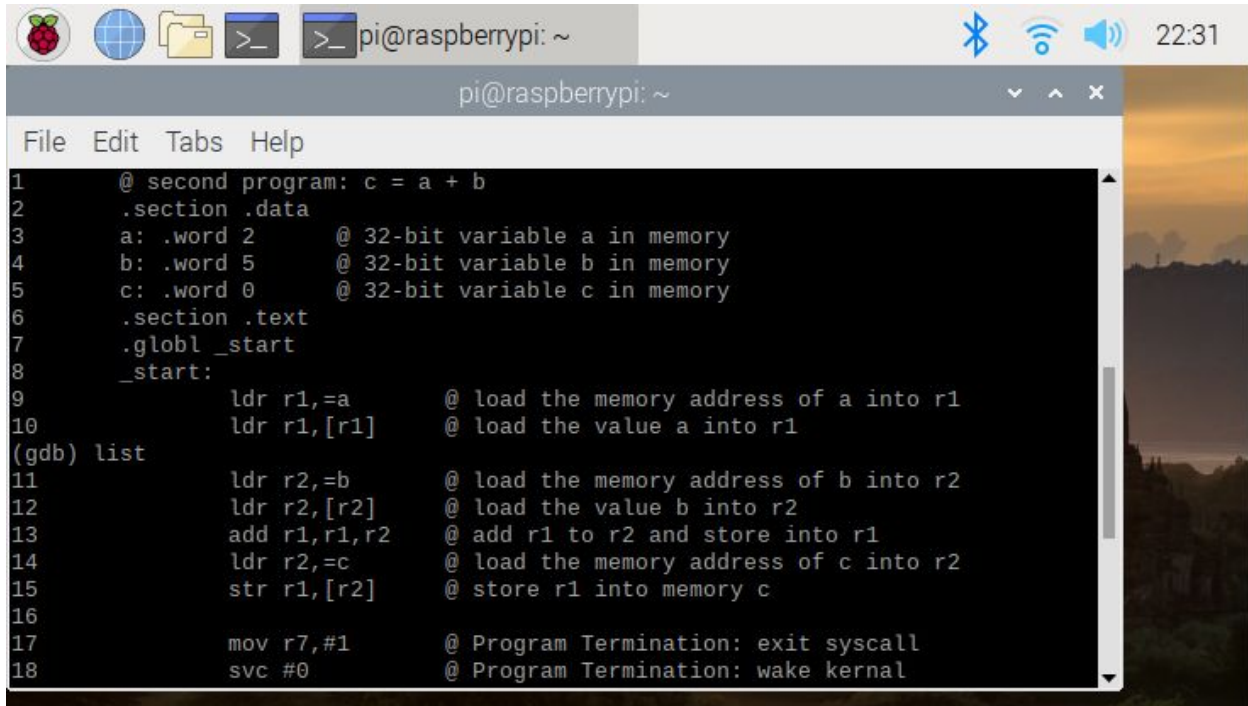
pi@raspberrypi:~ $ gdb second
GNU gdb (Raspbian 8.2.1-2) 8.2.1
Copyright (C) 2018 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "arm-linux-gnueabi".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from second...done.
(gdb) list
1      @ second program: c = a + b

```

Here I am compiling the second program and executing it with gdb then trying to show the code with the command (gdb) list.



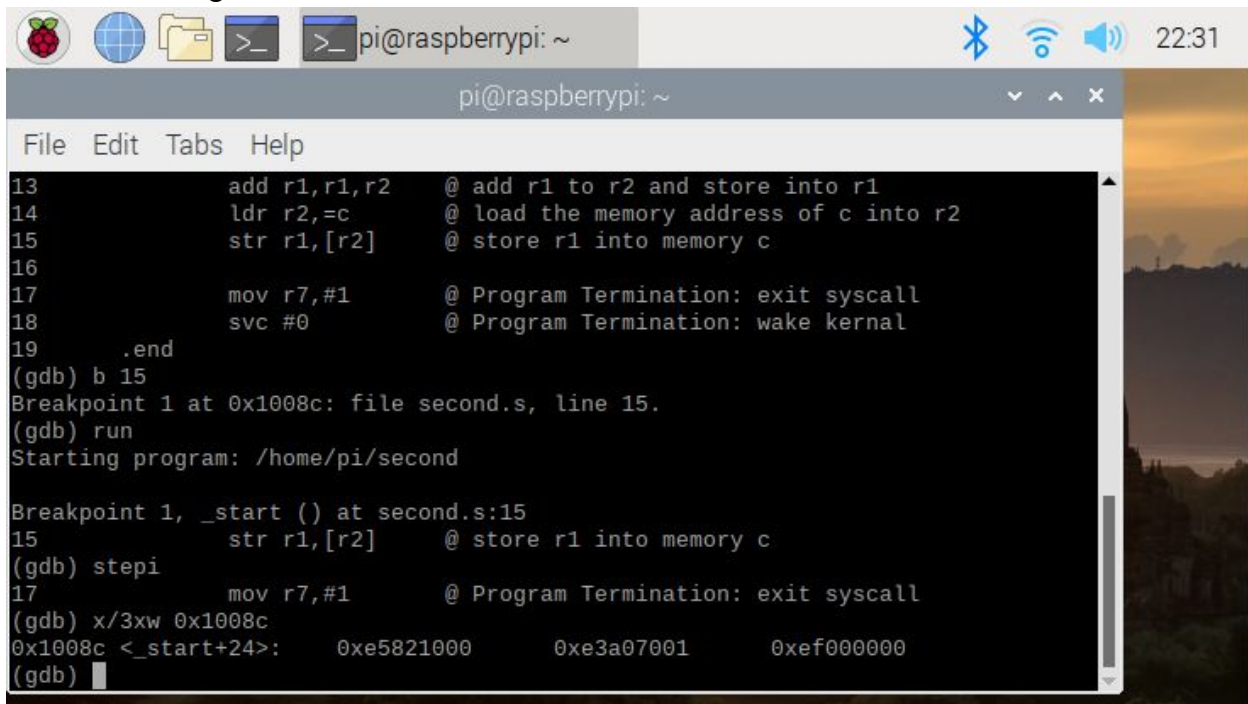


```

1  @ second program: c = a + b
2  .section .data
3  a: .word 2      @ 32-bit variable a in memory
4  b: .word 5      @ 32-bit variable b in memory
5  c: .word 0      @ 32-bit variable c in memory
6  .section .text
7  .globl _start
8  _start:
9      ldr r1,a      @ load the memory address of a into r1
10     ldr r1,[r1]   @ load the value a into r1
(gdb) list
11     ldr r2,b      @ load the memory address of b into r2
12     ldr r2,[r2]   @ load the value b into r2
13     add r1,r1,r2  @ add r1 to r2 and store into r1
14     ldr r2,c      @ load the memory address of c into r2
15     str r1,[r2]   @ store r1 into memory c
16
17     mov r7,#1     @ Program Termination: exit syscall
18     svc #0        @ Program Termination: wake kernal

```

This is the code for the program and what I noticed is instead of moving like in the last assignment's program we store variables in the .data then we load the memory address and the value into the register we want.



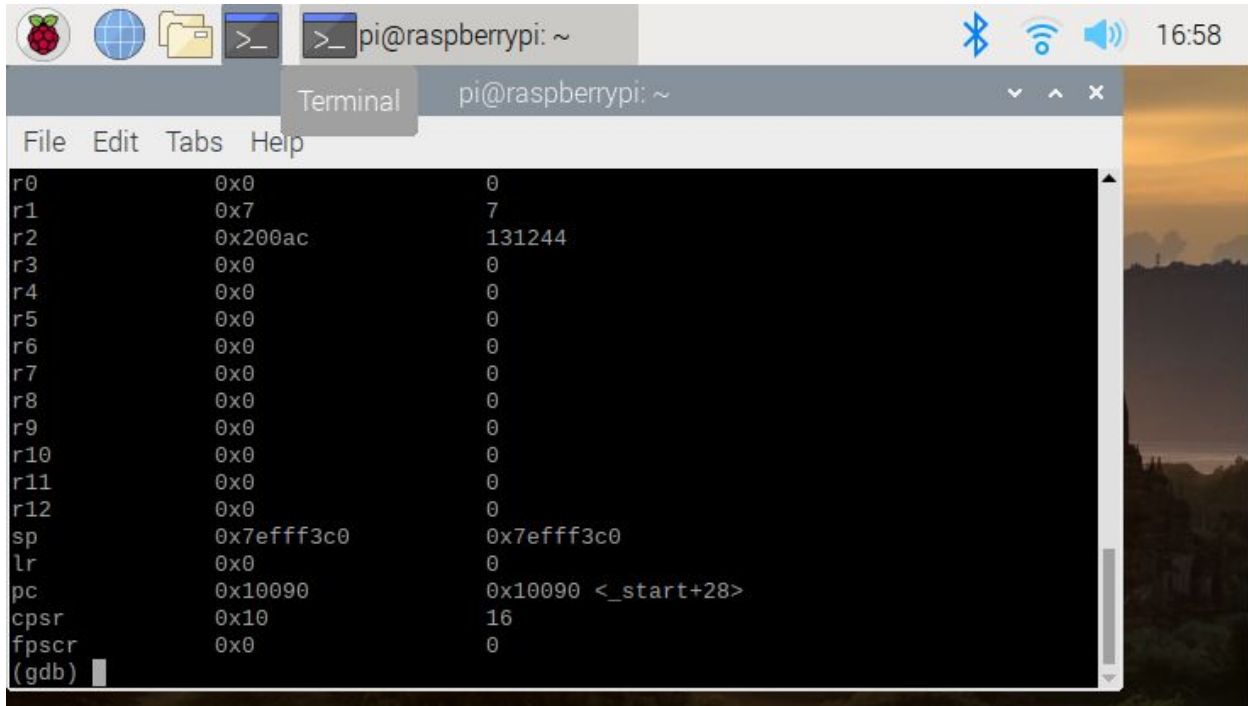
```

13     add r1,r1,r2  @ add r1 to r2 and store into r1
14     ldr r2,c      @ load the memory address of c into r2
15     str r1,[r2]   @ store r1 into memory c
16
17     mov r7,#1     @ Program Termination: exit syscall
18     svc #0        @ Program Termination: wake kernal
19     .end
(gdb) b 15
Breakpoint 1 at 0x1008c: file second.s, line 15.
(gdb) run
Starting program: /home/pi/second

Breakpoint 1, _start () at second.s:15
15     str r1,[r2]   @ store r1 into memory c
(gdb) stepi
17     mov r7,#1     @ Program Termination: exit syscall
(gdb) x/3xw 0x1008c
0x1008c <_start+24>:  0xe5821000    0xe3a07001    0xef000000
(gdb)

```

Here I set the breakpoint at 15 so the code could run then I tested the stepi which allowed me to continue even though I set a breakpoint and I displayed the memory which shows 0xe5821000, 0xe3a07001, and 0xef000000.



The screenshot shows a terminal window on a Raspberry Pi. The title bar indicates the user is 'pi' at 'raspberrypi'. The terminal displays the output of the 'gdb' command, showing the current state of registers and memory. The registers listed are r0 through r12, sp, lr, pc, cpsr, and fpscr. The values for r0 through r12 are mostly 0, except for r1 which is 7 and r2 which is 131244. The stack pointer (sp) is 0x7efff3c0. The program counter (pc) is 0x10090, which is labeled as '<\_start+28>'. The control status register (cpsr) is 16, and the floating-point status register (fpscr) is 0. The prompt '(gdb)' is visible at the bottom.

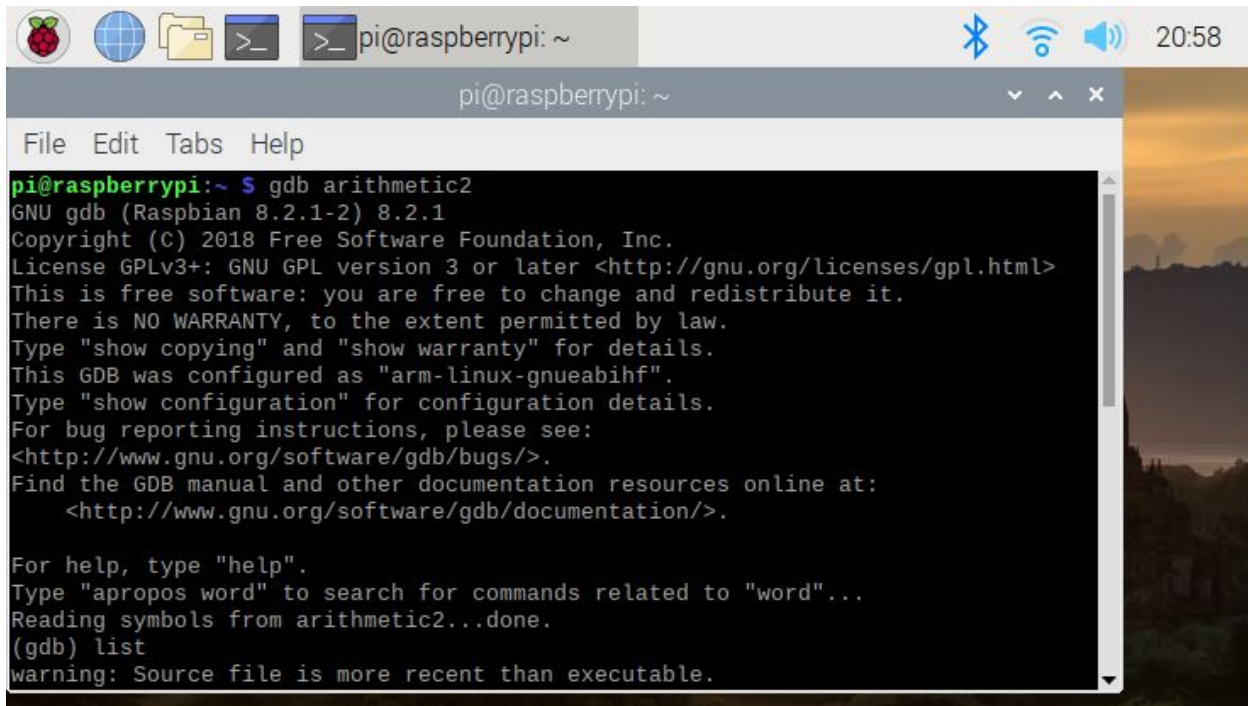
```

r0          0x0          0
r1          0x7          7
r2          0x200ac      131244
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          0x10090      0x10090 <_start+28>
cpsr        0x10        16
fpscr       0x0          0
(gdb)

```

Here the value in register 1 is 7 because I added 5 and 2 then stored it into register 1 and in register 2 that is the memory address of c.

## Part 2:



The screenshot shows a terminal window on a Raspberry Pi. The title bar indicates the user is 'pi' at 'raspberrypi'. The terminal displays the output of the 'gdb arithmetic2' command. It shows the GNU GDB version (8.2.1-2) and the copyright information. The prompt '(gdb)' is visible at the bottom.

```

pi@raspberrypi:~ $ gdb arithmetic2
GNU gdb (Raspbian 8.2.1-2) 8.2.1
Copyright (C) 2018 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "arm-linux-gnueabi".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
  <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from arithmetic2...done.
(gdb) list
warning: Source file is more recent than executable.

```

Here I am compiling and executing the arithmetic2 program

```

1  @second arithmetic program
2  .section .data
3  val1: .word 6          @ 32-bit variable val1 in memory
4  val2: .word 11         @ 32-bit variable val2 in memory
5  val3: .word 16         @ 32-bit variable val3 in memory
6  .section .text
7  .globl _start
8  _start:
9  ldr r1,=val1           @ load the memory address of val1 into r1
10 ldr r1,[r1]            @ load the value val1 into r1
(gdb)
11 ldr r2,=val2           @ load the memory address of val2 into r2
12 ldr r2,[r2]            @ load the value val2 into r2
13 ldr r3,=val3           @ load the memory address of val3 into r3
14 ldr r3,[r3]            @ load the value val3 into r3
15 add r2,r2,#9           @ adding 9 to r2
16 add r2,r2,r3           @ adding r3 to r2
17 sub r2,r2,r1           @ subtracting r1 from r2
18

```

Here is my code which I first stored the immediate values inside variables in the .data. I then loaded different registers with the memory address and value of a certain variable. For example I loaded register 1 with val1's memory address and value of 6. I then did arithmetic with the registers to get my answer of 30 which is 1E in hex.

```

(gdb) x/3xw 0x10098
0x10098 <_start+36>:    0xe3a07001    0xef000000    0x000200ac
(gdb) info registers
r0             0x0             0
r1             0x6             6
r2             0x1e            30
r3             0x10            16
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>

```

Here I am displaying the memory and the info registers which show that in my register 2 I get my desired value which is 30 and 1E in hex. In register 1 it is 6 and in register 3 it is 16 because

that was the initial value I loaded it with. It stayed the same because I only used them to add and sub to register 2.

### **Parallel Programming Skills Foundation: Miguel Romo**

- **Identifying the components on the raspberry PI B+**
  - ◆ USB, ethernet, ethernet controller, camera, HDMI, power, display, and CPU/RAM.
- **How many cores does the Raspberry Pi's B+ CPU have**
  - ◆ The Raspberry Pi's B+ CPU has a quad-core multicore CPU.
- **List three main differences between X86 (CISC) and ARM Raspberry PI (RISC). Justify your answer and use your own words (do not copy and paste).**
  - ◆ CISC has more processing power and has an instruction set that can perform complex instructions to access memory. ARM has a simple instruction set that can be executed more quickly. CISC put less effort on the compiler and relies on more hardware to decode and execute instructions. ARM has less hardware and relies on the compiler to decode and execute instructions. ARM can execute instructions more quickly and CISC.
- **What is the difference between sequential and parallel computation and identify the practical significance of each?**
  - ◆ Sequential computation completes a task one by one, only uses one processor, and requires more time to complete a task. Parallel computation completes multiple tasks at a time, multiple processors are used, and requires less time to complete tasks.
- **Identify the basic form of data and task parallelism in computational problems.**
  - ◆ Data parallelism refers to a broad category of parallelism in which the same computation is applied to multiple data items. Task parallelism applies to solutions where parallelism is organized around the functions to be performed rather than around the data.
- **Explain the differences between processes and threads.**
  - ◆ Threads share access to the memory, so threads can communicate with other threads by reading from or writing to memory that is visible to them all. A process is a thread of control that has its own private address space.
- **What is OpenMP and what is OpenMP pragmas?**
  - ◆ OpenMP is a low-level thread package that allows shared memory multiprocessor programming on different operating systems. OpenMP programs is a compiler directive that enables the compiler to generate threaded codes.
- **What applications benefit from multi-core (list four)?**
  - ◆ Database servers
  - ◆ Web servers
  - ◆ Compilers
  - ◆ Multimedia applications
- **Why Multicore? (why not single core, list four)**
  - ◆ To process more tasks, single-core clock frequencies are too slow and deliver lower performance.
  - ◆ Higher performance



- ◆ Lower energy cost
- ◆ Lower power cost

### Parallel Programming Basics: Miguel Romo

```

GNU nano 3.2 spmd2.c Modified
#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 {
        id = omp_get_thread_num();
        numThreads = omp_get_num_threads();
        printf("Hello from thread %d of %d\n", id, numThreads);
    }
    printf("\n");
    return 0;
}

```

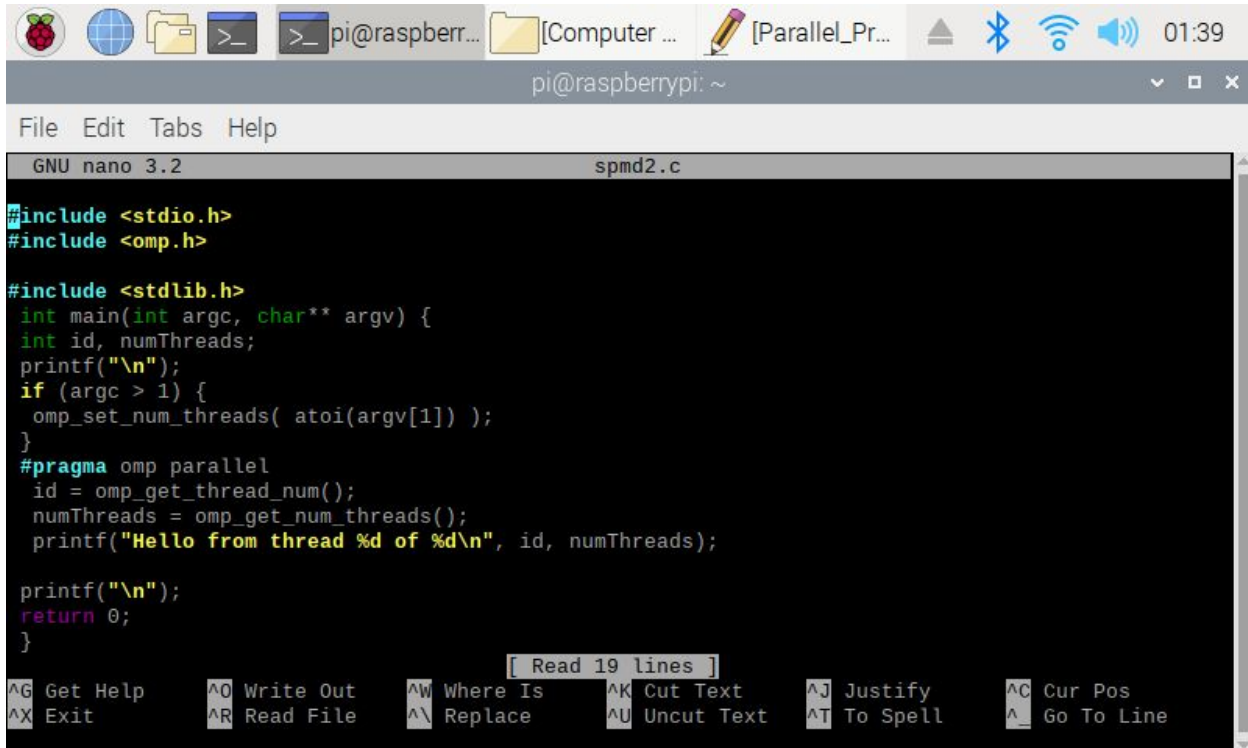
Code was compiled and saved.

```

pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
spmd2.c:3:19: error: missing terminating > character
#include <stdlib.h>
^
spmd2.c: In function 'main':
spmd2.c:10:23: error: expected '#pragma omp' clause before '{' token
#pragma omp parallel {
^
spmd2.c: At top level:
spmd2.c:15:9: error: expected declaration specifiers or '...' before string constant
printf("\n");
^
spmd2.c:16:2: error: expected identifier or '(' before 'return'
return 0;
^
spmd2.c:17:2: error: expected identifier or '(' before '}' token
}
^
pi@raspberrypi:~ $ nano spmd2.c
pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
spmd2.c: In function 'main':
spmd2.c:10:3: error: invalid preprocessing directive #program; did you mean #pragma?
#pragma omp parallel
^

```

Executable program was created, and ran, but errors were found.



```

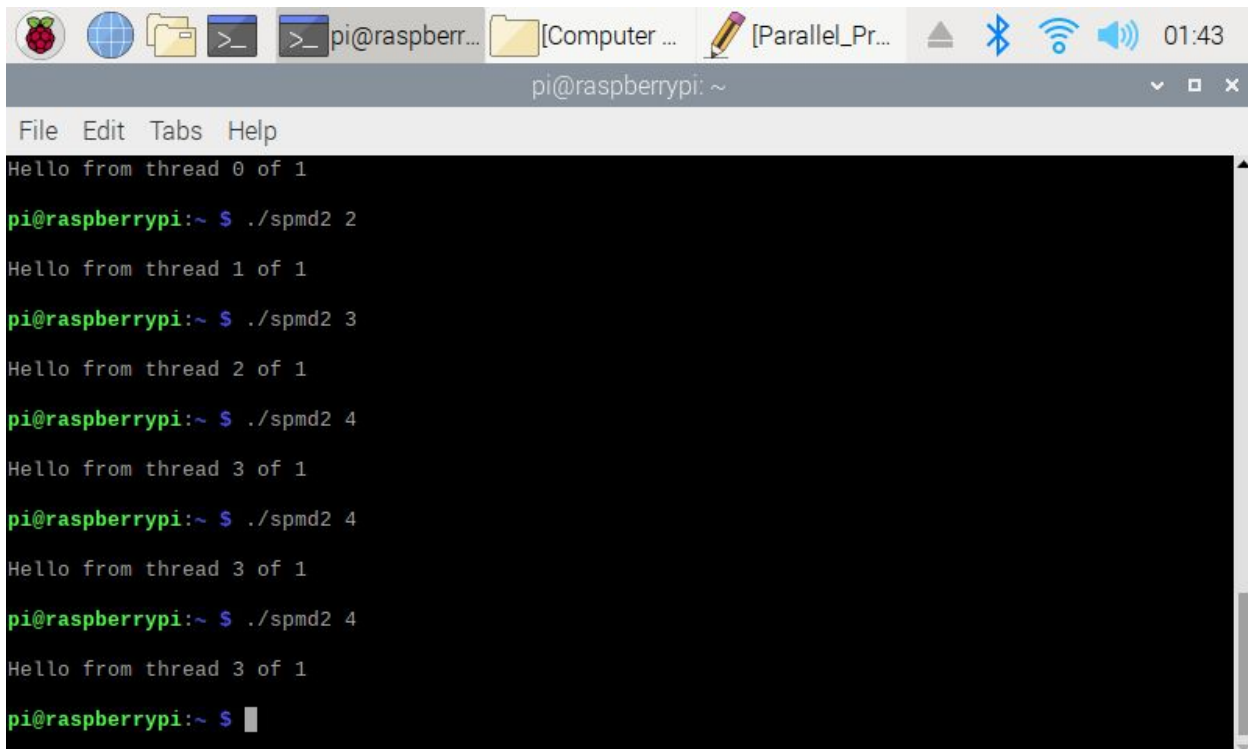
GNU nano 3.2                                spmd2.c
#include <stdio.h>
#include <omp.h>

#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
        id = omp_get_thread_num();
        numThreads = omp_get_num_threads();
        printf("Hello from thread %d of %d\n", id, numThreads);

    printf("\n");
    return 0;
}
[ Read 19 lines ]
^G Get Help      ^O Write Out    ^W Where Is    ^K Cut Text    ^J Justify     ^C Cur Pos
^X Exit          ^R Read File    ^\ Replace     ^U Uncut Text  ^T To Spell    ^_ Go To Line

```

Errors in the code were corrected.



```

pi@raspberrypi:~ $ ./spmd2 2
Hello from thread 0 of 1

pi@raspberrypi:~ $ ./spmd2 3
Hello from thread 0 of 1
Hello from thread 1 of 1

pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 0 of 1
Hello from thread 1 of 1
Hello from thread 2 of 1

pi@raspberrypi:~ $ ./spmd2 4
Hello from thread 0 of 1
Hello from thread 1 of 1
Hello from thread 2 of 1
Hello from thread 3 of 1

pi@raspberrypi:~ $

```

Program ran successfully but the same thread id number appears more than once.

```

GNU nano 3.2      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;
}
^G Get Help      ^O Write Out     ^W Where Is      ^K Cut Text      ^J Justify       ^C Cur Pos
^X Exit          ^R Read File     ^\ Replace       ^U Uncut Text    ^T To Spell      ^_ Go To Line

```

In order to fix this we need to declare our variables inside the block where the program will be forked and run in parallel on separate threads.

```

pi@raspberrypi:~ $ gcc spmd2.c -o spmd2 -fopenmp
pi@raspberrypi:~ $ ./spmd2 4

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

pi@raspberrypi:~ $ ./spmd2 4

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

pi@raspberrypi:~ $ ./spmd2 4

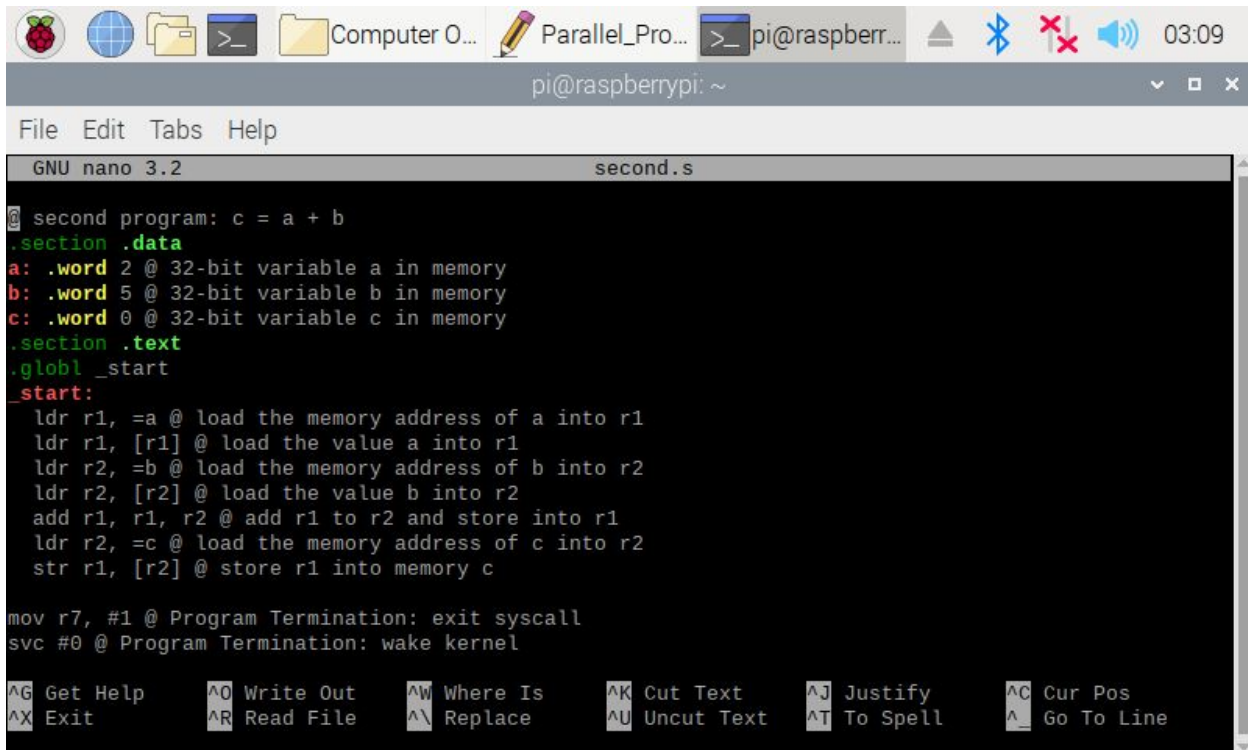
Hello from thread 0 of 4
Hello from thread 1 of 4
Hello from thread 3 of 4
Hello from thread 2 of 4

pi@raspberrypi:~ $

```

After declaring the variable in the right place, we can see that different threads IDs are now being used.

**ARM Assembly Programming: Miguel Romo**



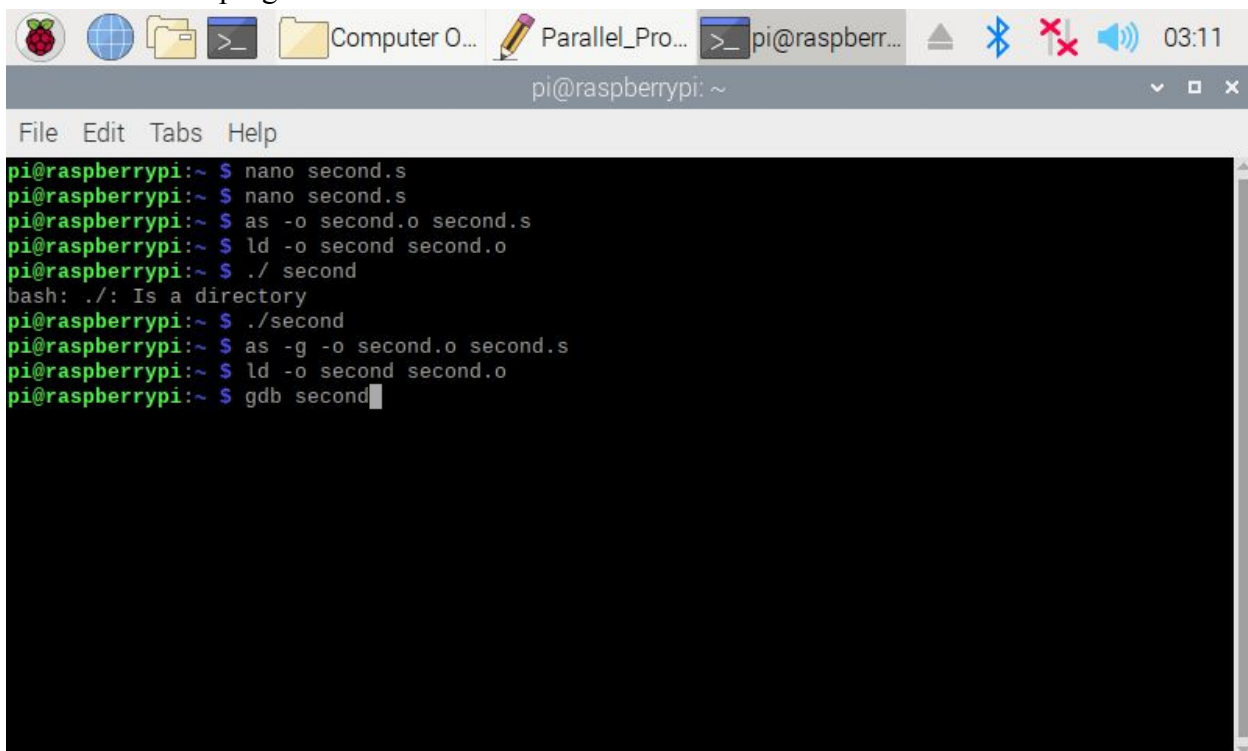
```

GNU nano 3.2 second.s
@ second program: c = a + b
.section .data
a: .word 2 @ 32-bit variable a in memory
b: .word 5 @ 32-bit variable b in memory
c: .word 0 @ 32-bit variable c in memory
.section .text
.globl _start
_start:
    ldr r1, =a @ load the memory address of a into r1
    ldr r1, [r1] @ load the value a into r1
    ldr r2, =b @ load the memory address of b into r2
    ldr r2, [r2] @ load the value b into r2
    add r1, r1, r2 @ add r1 to r2 and store into r1
    ldr r2, =c @ load the memory address of c into r2
    str r1, [r2] @ store r1 into memory c

mov r7, #1 @ Program Termination: exit syscall
svc #0 @ Program Termination: wake kernel

^G Get Help    ^O Write Out   ^W Where Is    ^K Cut Text    ^J Justify     ^C Cur Pos
^X Exit        ^R Read File   ^\ Replace     ^U Uncut Text  ^T To Spell    ^_ Go To Line
  
```

Code for second program.



```

pi@raspberrypi:~ $ nano second.s
pi@raspberrypi:~ $ nano second.s
pi@raspberrypi:~ $ as -o second.o second.s
pi@raspberrypi:~ $ ld -o second second.o
pi@raspberrypi:~ $ ./second
bash: ./: Is a directory
pi@raspberrypi:~ $ ./second
pi@raspberrypi:~ $ as -g -o second.o second.s
pi@raspberrypi:~ $ ld -o second second.o
pi@raspberrypi:~ $ gdb second
  
```

The commands used to create a file name for the program, and assemble link and run program. No output is shown in the terminal window, so we put the program in debug by using the GDB commands to examine the contents of the registers and memory.



```

pi@raspberrypi:~ $ ld -o second second.o
pi@raspberrypi:~ $ gdb second
GNU gdb (Raspbian 8.2.1-2) 8.2.1
Copyright (C) 2018 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "arm-linux-gnueabi".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from second...done.
(gdb) (gdb) list
Undefined command: "". Try "help".
(gdb) list
1      @ second program: c = a + b
2      .section .data
3      a: .word 2 @ 32-bit variable a in memory

```

Here we use the list command to view the code and see where to set the breakpoint.

```

10      ldr r1, [r1] @ load the value a into r1
(gdb)
11      ldr r2, =b @ load the memory address of b into r2
12      ldr r2, [r2] @ load the value b into r2
13      add r1, r1, r2 @ add r1 to r2 and store into r1
14      ldr r2, =c @ load the memory address of c into r2
15      str r1, [r2] @ store r1 into memory c
16
17      mov r7, #1 @ Program Termination: exit syscall
18      svc #0 @ Program Termination: wake kernel
19      .end
(gdb) b15
Undefined command: "b15". Try "help".
(gdb) b 15
Breakpoint 1 at 0x1008c: file second.s, line 15.
(gdb) run
Starting program: /home/pi/second

Breakpoint 1, _start () at second.s:15
15      str r1, [r2] @ store r1 into memory c
(gdb) x/3xw 0x1008c
0x1008c <_start+24>:  0xe5821000      0xe3a07001      0xef000000
(gdb)

```

After setting the breakpoint on line 15, we run the program and use the memory command to examine the contents.

```

GNU nano 3.2 arithmetic2.s
@ arithmetic2 program Register = val2 + 9 + val3 - val1
val1: .word 6 @ 32-bit variable val1 in memory
val2: .word 11 @ 32-bit variable val2 in memory
val3: .word 16 @ 32-bit variable val3 in memory
.section .text
.globl _start
_start:
    ldr r1, =val1 @ load the memory address of val1 into r1
    ldr r1, [r1] @ load the value val1 into r1
    ldr r2, =val2 @ load the memory address of val2 into r2
    ldr r2, [r2] @ load the value val2 into r2
    ldr r3, =val3 @ load the memory address of val3 into r3
    ldr r3, [r3] @ load the value val3 into r3
    add r2, r2, #9 @ add 9 to r2 and store into r2
    add r2, r3, r2 @ add r3 to r2 and store into r2
    sub r2, r1, r2 @ subtract r1 from r2 and store into r2

mov r7, #1 @ Program Termination: exit syscall

^G Get Help    ^O Write Out   ^W Where Is    ^K Cut Text    ^J Justify     ^C Cur Pos
^X Exit        ^R Read File   ^\ Replace     ^U Uncut Text  ^T To Spell    ^_ Go To Line

```

Code for arithmetic2

```

(gdb) quit
A debugging session is active.

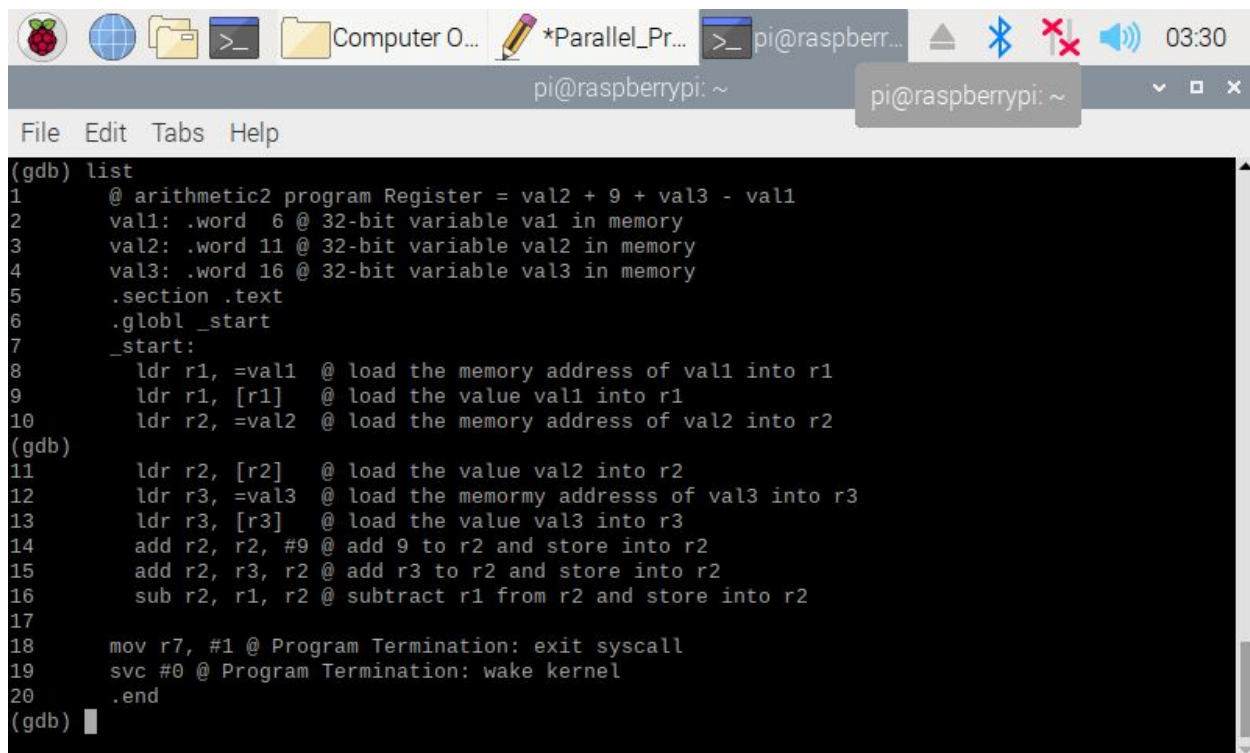
    Inferior 1 [process 833] will be killed.

Quit anyway? (y or n) y
pi@raspberrypi:~ $ nano arithmetic2.s
pi@raspberrypi:~ $ as -o arithmetic2.o arithmetic2.s
arithmetic2.s: Assembler messages:
arithmetic2.s:14: Error: immediate expression requires a # prefix -- `add r2,9,r2'
pi@raspberrypi:~ $ nano arithmetic2.s
pi@raspberrypi:~ $ as -o arithmetic2.o arithmetic2.s
arithmetic2.s: Assembler messages:
arithmetic2.s:14: Error: constant expression expected -- `add r2,#9,r2'
pi@raspberrypi:~ $ nano arithmetic2.s
pi@raspberrypi:~ $ as -o arithmetic2.o arithmetic2.s
pi@raspberrypi:~ $ ld -o arithmetic2 arithmetic2.o
pi@raspberrypi:~ $ ./arithmetic2
bash: ./: Is a directory
pi@raspberrypi:~ $ ./arithmetic2
pi@raspberrypi:~ $ as -g -o arithmetic2.o arithmetic2.s
pi@raspberrypi:~ $ ld -o arithmetic2 arithmetic2.o
pi@raspberrypi:~ $ ld -o arithmetic2.o arithmetic2.o
pi@raspberrypi:~ $

```

The commands used to create a file name for the program, and assemble link and run program. No output is shown in the terminal window, so we put the program in debug by using the GDB commands to examine the contents of the registers and memory. I had errors in my code because I forgot to place the '#' in front of the integer and didn't place it in the right spot.



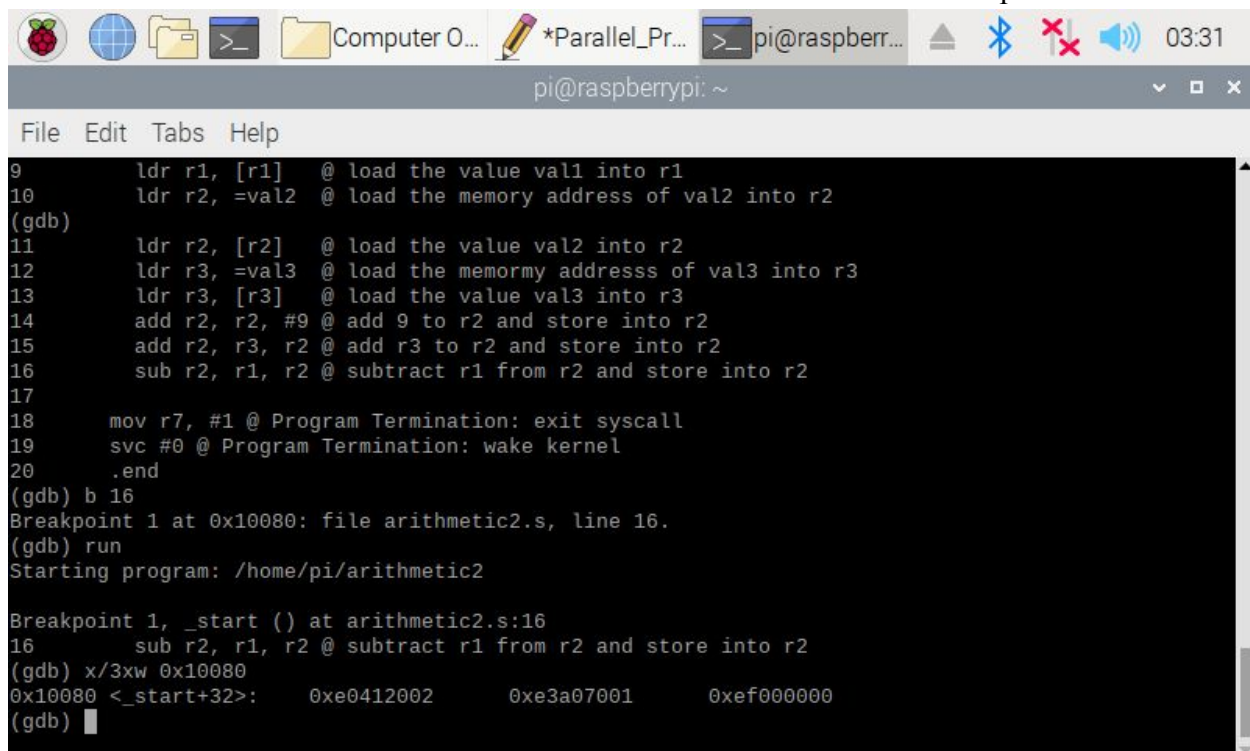


```

(gdb) list
1      @ arithmetic2 program Register = val2 + 9 + val3 - val1
2      val1: .word 6 @ 32-bit variable val1 in memory
3      val2: .word 11 @ 32-bit variable val2 in memory
4      val3: .word 16 @ 32-bit variable val3 in memory
5      .section .text
6      .globl _start
7      _start:
8      ldr r1, =val1 @ load the memory address of val1 into r1
9      ldr r1, [r1] @ load the value val1 into r1
10     ldr r2, =val2 @ load the memory address of val2 into r2
(gdb)
11     ldr r2, [r2] @ load the value val2 into r2
12     ldr r3, =val3 @ load the memormy addresss of val3 into r3
13     ldr r3, [r3] @ load the value val3 into r3
14     add r2, r2, #9 @ add 9 to r2 and store into r2
15     add r2, r3, r2 @ add r3 to r2 and store into r2
16     sub r2, r1, r2 @ subtract r1 from r2 and store into r2
17
18     mov r7, #1 @ Program Termination: exit syscall
19     svc #0 @ Program Termination: wake kernel
20     .end
(gdb)

```

Here we use the list command to view the code and see where to set the breakpoint.



```

9      ldr r1, [r1] @ load the value val1 into r1
10     ldr r2, =val2 @ load the memory address of val2 into r2
(gdb)
11     ldr r2, [r2] @ load the value val2 into r2
12     ldr r3, =val3 @ load the memormy addresss of val3 into r3
13     ldr r3, [r3] @ load the value val3 into r3
14     add r2, r2, #9 @ add 9 to r2 and store into r2
15     add r2, r3, r2 @ add r3 to r2 and store into r2
16     sub r2, r1, r2 @ subtract r1 from r2 and store into r2
17
18     mov r7, #1 @ Program Termination: exit syscall
19     svc #0 @ Program Termination: wake kernel
20     .end
(gdb) b 16
Breakpoint 1 at 0x10080: file arithmetic2.s, line 16.
(gdb) run
Starting program: /home/pi/arithmetic2

Breakpoint 1, _start () at arithmetic2.s:16
16     sub r2, r1, r2 @ subtract r1 from r2 and store into r2
(gdb) x/3xw 0x10080
0x10080 <_start+32>: 0xe0412002 0xe3a07001 0xef000000
(gdb)

```

After setting the breakpoint on line 16, we run the program and use the memory command to examine the contents.

## Appendix

**Slack:** <https://app.slack.com/client/TSWLWS9LK/CT8581ZU0>

**Github:** <https://github.com/Arteenghafourikia/CSC3210-TheCommuters>

**Youtube:** <https://youtu.be/hIdJnpbeZVQ>

The screenshot shows a GitHub Project board for the repository 'Arteenghafourikia / CSC3210-TheCommuters'. The board is titled 'Project A2' and was updated 3 days ago. It features three columns: 'To do' (4 items), 'In progress' (2 items), and 'Done' (4 items). Each item is a card with a title, a checkbox, and the user who added it. A search bar and a '+ Add column' button are also visible.

Column	Item	Added by
To do	<input type="checkbox"/> Presentation	Arteenghafourikia
	<input type="checkbox"/> Do the ARM Assembly Programming	Arteenghafourikia
	<input type="checkbox"/> Parallel Programming Skills	Arteenghafourikia
	<input type="checkbox"/> Report	Arteenghafourikia
In progress	<input type="checkbox"/> Getting the report together	Arteenghafourikia
	<input type="checkbox"/> Using Slack	Arteenghafourikia
Done	<input type="checkbox"/> Parallel Programming	Arteenghafourikia
	<input type="checkbox"/> ARM Assembly Programming	Arteenghafourikia
	<input type="checkbox"/> Scheduling and Planning spreadsheet	ashack1
	<input type="checkbox"/> Project Descriptions on Github	Arteenghafourikia