Gcc trapnotThe Assemblers
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Developing Soft and Parallel Programming Skills Using Project-Based Learning

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Planning and Scheduling

Assignee Name	Email	Task	Duration (hours)	Dependency	Due Date	Note

	(@student.gsu.edu)				(March 8th)	
Aaja Christie (Coordinator)	achristie3	Task 2 Task 4	5	Github Slack Raspberry pi 3 B+	March 7th	
Davidson Fleurantin	dfleurantin1	Parallel Programming	3	Raspberry pi 3 B+	March 4th	
Mamadou Diallo	mdiallo15	Task 5 Report	2	Google Docs	March 7	
Sheng Chen	schen36	Task 6 Video editing	2	Adobe Premiere Pro CC 2018	March 7	
Matthew Kabat	mkabat1	Task 3A	2		March 7th	

Task 3: Programming Skills

Foundations

1. **Define the following**:

- Task - a discrete program or set of instructions that is run by the processor. Multiple tasks are done by multiple processors in a parallel program.

- Pipelining - the process of breaking down a task into discrete chunks that can each be done by a different processing unit

- Shared Memory -
  - Hardware View: All processors have direct access to common physical memory.
  - Software View: All tasks have same view of memory and can access memory regardless of its physical location.

- Communications - exchanging data to do parallel computing

- Synchronization - the coordination of parallel tasks in real time. Often implemented by establishing synchronization points in an application.

2. Classify parallel computers based on Flynn's taxonomy. Briefly describe every one of them.

- Single Instruction, Single Data (SISD): a single processing unit performs one instruction upon one piece of data at a time.
- Single Instruction, Multiple Data (SIMD): multiple processing units perform the same instruction upon different pieces of data.
- Multiple Instruction, Single Data (MISD): multiple processing units perform different instructions upon a single piece of data.
- Multiple Instruction, Multiple Data (MIMD): multiple processing units perform different instructions upon different pieces of data.

3. What are the Parallel Programming Models?

Parallel programming models are different ways to implement parallel computing. Examples include Shared Memory, Distributed Memory, and Threads.

4. List and briefly describe the types of Parallel Computer Memory Architectures. What type is used by OpenMP and why?

- Shared Memory Model (without threads):
  - processes/tasks share a common address space, which they read and write to asynchronously
  - Various mechanisms such as locks / semaphores are used to control access to the shared memory, resolve contentions and to prevent race conditions and deadlocks.
- Shared Memory Model (with threads):

    - A single "heavy weight" process has multiple "light weight", concurrent execution paths called threads
    - Each thread has local data, but also, shares the entire resources of the main program
- OpenMP uses a threaded Shared Memory model. This allows for greater portability and increased ease of use for the programmer.

5. Compare Shared Memory Model with Threads Model? (in your own words and show pictures)
The main difference is that an unthreaded Shared Memory Model is far more intensive to setup and manage. However, it does make communication of data easier because data is not “owned” in this model.

6. What is Parallel Programming? (in your own words) -
Parallel programming is when you have multiple processing units acting in a single machine or cluster to solve a problem.

7. What is system on chip (SoC)? Does Raspberry PI use system on SoC? -
A System-on-a-Chip integrates several discrete features into a single chip. They usually contain a CPU, GPU, memory, a USB controller, power management circuits, and wireless radios. The Raspberry Pi uses a SoC which contains a CPU, GPU, and RAM.

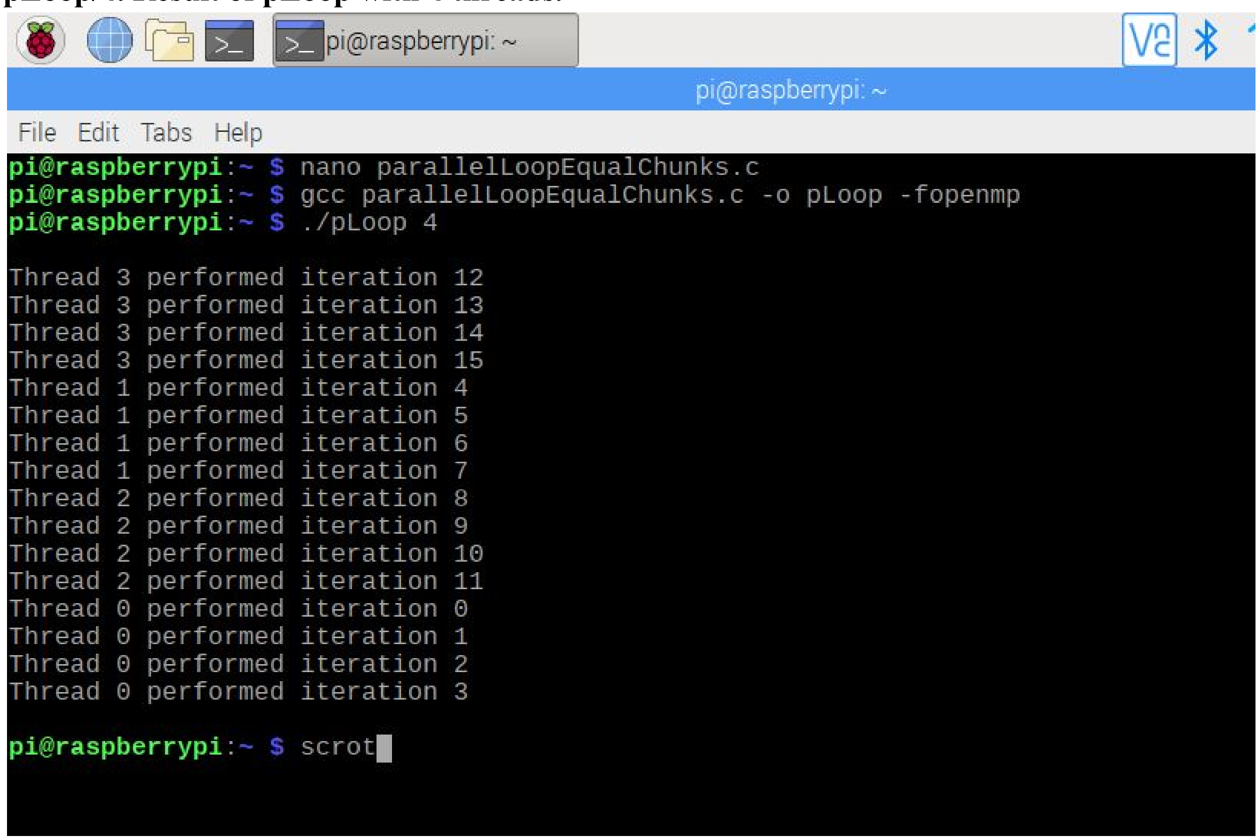
8. Explain what the advantages are of having a System on a Chip rather than separate CPU, GPU and RAM components.
For only a slight increase in size over a CPU, a SOC has far more functionality. Because various components are integrated, the absolute minimum size of a device using a SOC is greatly reduced when compared to a device with a discrete CPU. In addition, SOCs use significantly less power due to the components being physically closer and thus requiring less wiring. Finally, building a computer using SOCs is cheaper because fewer discrete physical chips are necessary.

Parallel Programming

Code 1 image. pLoop: Illustration of OpenMP's default parallel for loop

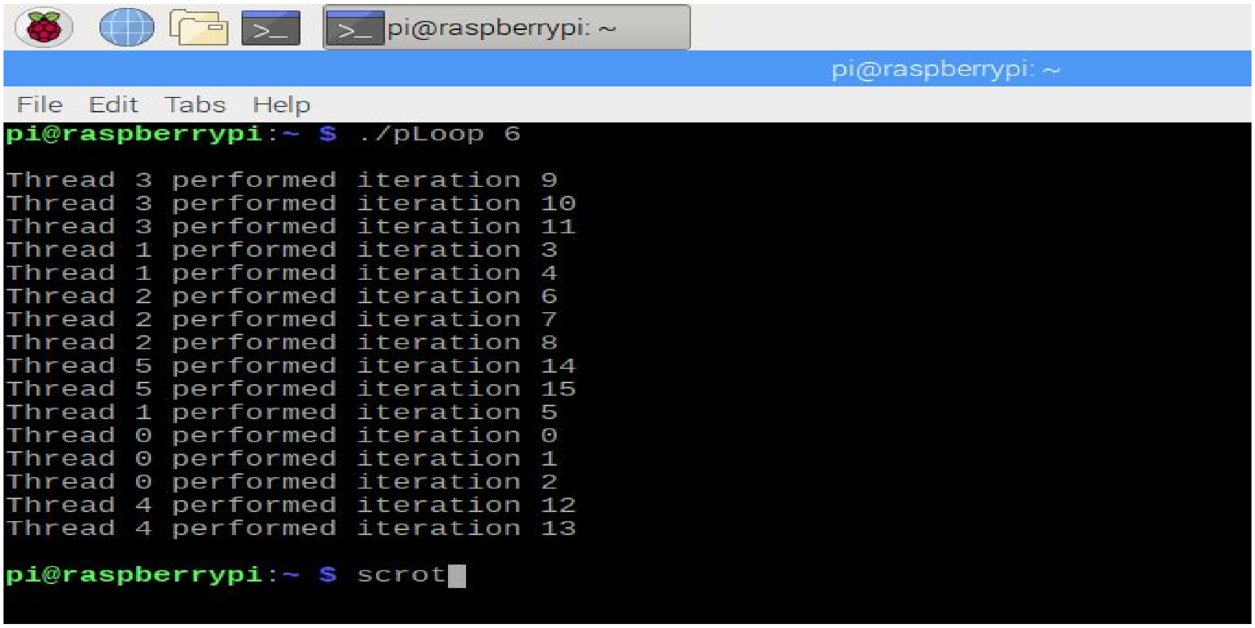
```
#include <stdio.h> // printf()
#include <stdlib.h> // atoi()
#include <omp.h> // OpenMP

int main(int argc, char** argv){
const int REPS = 16;

printf("\n");
if(argc>1){
 omp_set_num_threads(atoi(argv[1]));
 }

#pragma omp parallel for
for(int i=0;i<REPS;i++){
 int id= omp_get_thread_num();
 printf("Thread %d performed iteration %d\n", id,i);
}

printf("\n");
return 0;
}
```

pLoop/4. Result of pLoop with 4 threads.



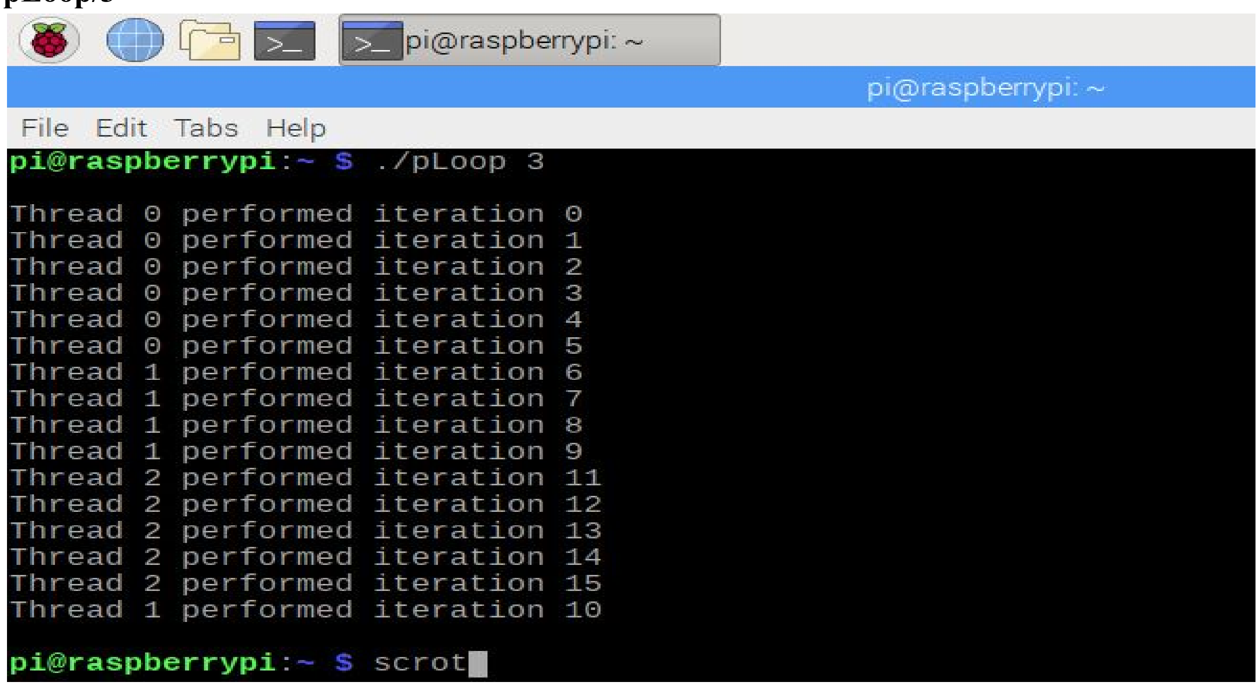
This is the result when pLoop ran on 4 threads. The loop has 16 iterations, and each thread will perform 4 iterations. The OpenMP pragma is applied in front of the loop.

pLoop/6. Code ran on 6 threads



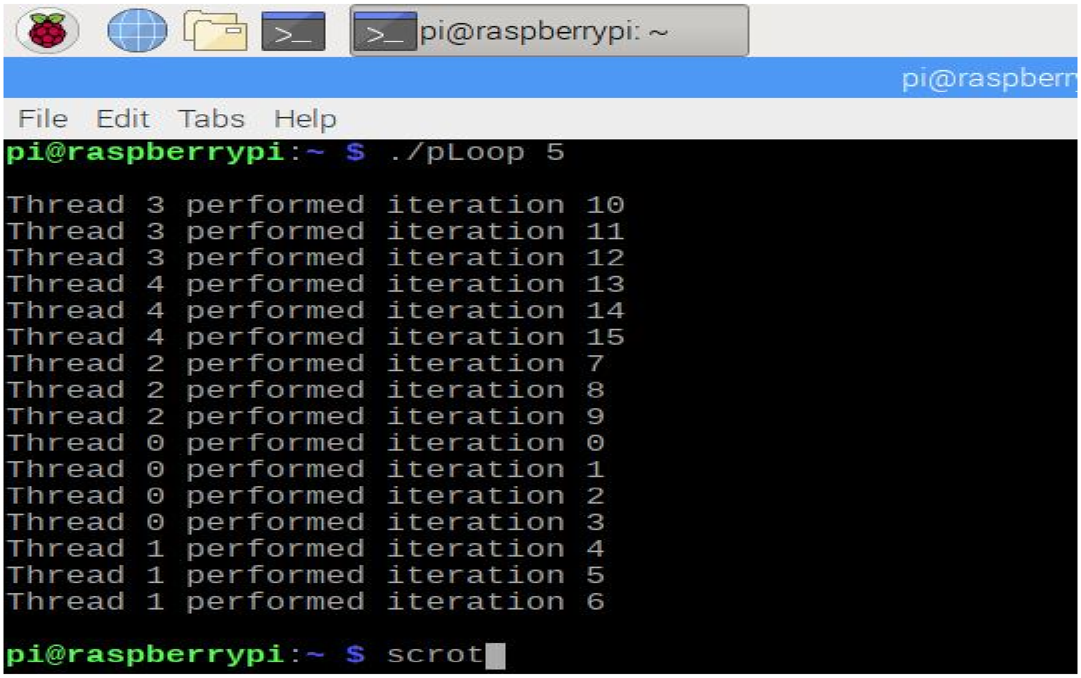
When the code ran on 6 threads, some threads performed 2 iterations, others performed 3 iterations. The first 4 threads (0-3) has 3 iterations, the last 2 (4,5) has two iterations.

pLoop/3



With the number of threads not divisible by 16, the first thread ran 6 iterations, threads 1 and 2 ran 5 iterations each. The first thread runs the most iterations, then it goes down from there.

pLoop/5



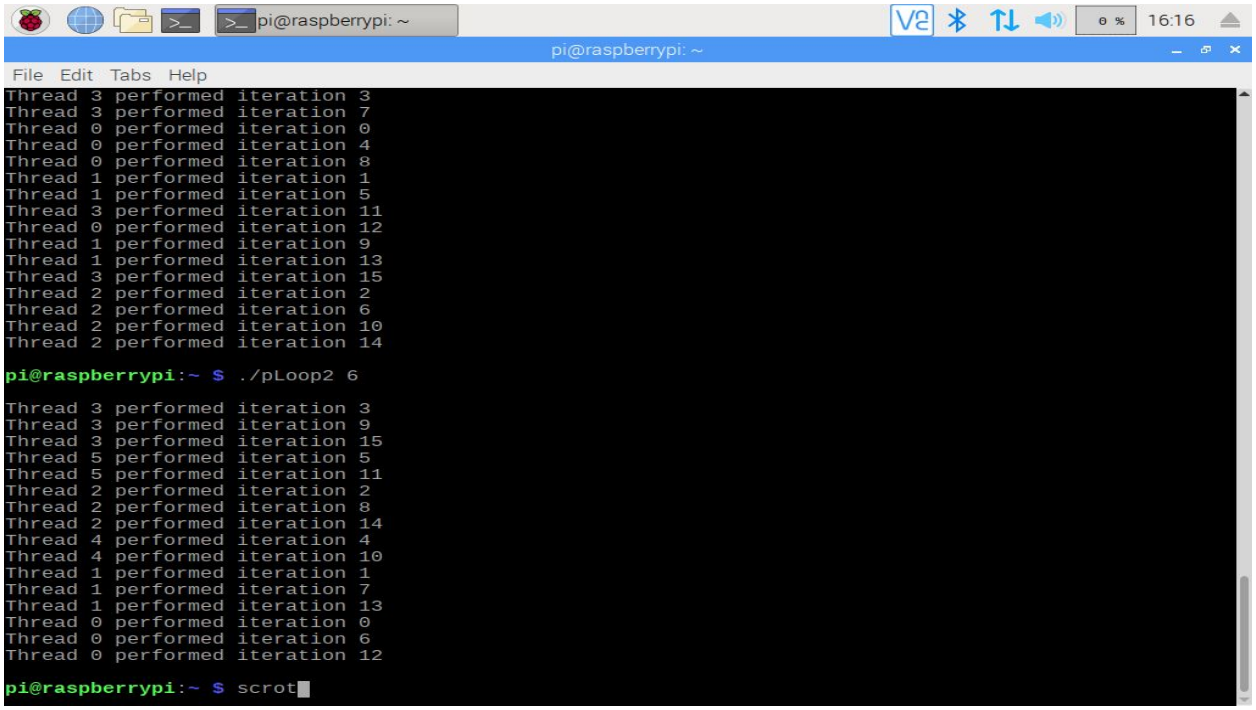
With 5 threads running the program, the first thread (0) runs the most iterations (4), then the remaining threads run 3 iterations each.

Code 2. Loop iteration in chunks of size 1 using OpenMP

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

int main(int argc, char** argv){
const int REPS = 16;
printf("\n");
if(argc>1){
omp_set_num_threads(atoi( argv[1]));
}
#pragma omp parallel for schedule(static,1)
for(int i=0;i<REPS;i++){
int id=omp_get_thread_num();
printf("Thread %d performed iteration %d\n",id,i);
}
/*
printf("\n---\n\n");
#pragma omp parallel
{
int id=omp_get_thread_num();
int numThreads=omp_get_num_threads();
for(int i=id;i<REPS;i+=numThreads){
printf("Thread %d performed iteration %d\n",id,i);
}
}
*/
printf("\n");
return 0;
}
```

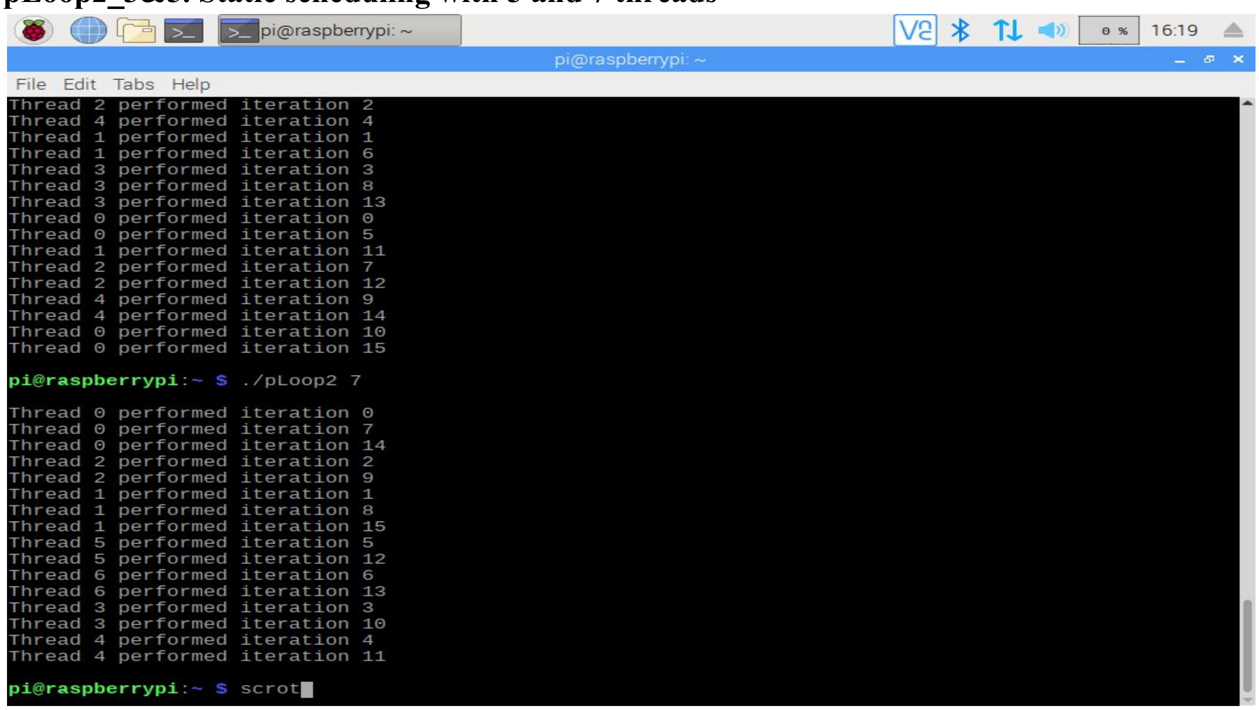
This code shows how OpenMP can use the first thread to do one iteration, the next one does the second iteration and so on until the last thread, when each thread does its iteration, the process starts again with the first thread. Each thread performs the same of work, this is called static scheduling.

pLoop2_4&6. The following image uses 4 and 6 threads



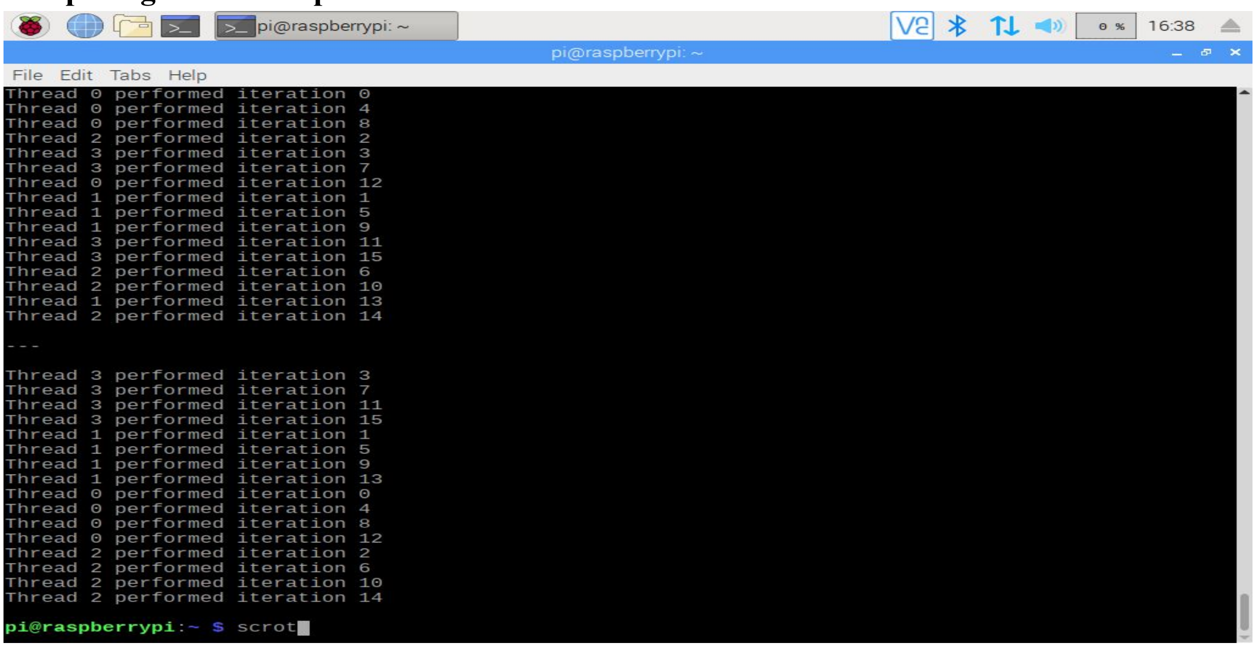
Static scheduling with 4 and 6 threads, the iterations on the top uses 4 threads. Thread 0 does iteration 0, thread 1 does iteration 1 and so on, then the process starts again with thread 0 doing iteration 4 and so on. The same is true using 6 threads.

pLoop2_3&5. Static scheduling with 5 and 7 threads



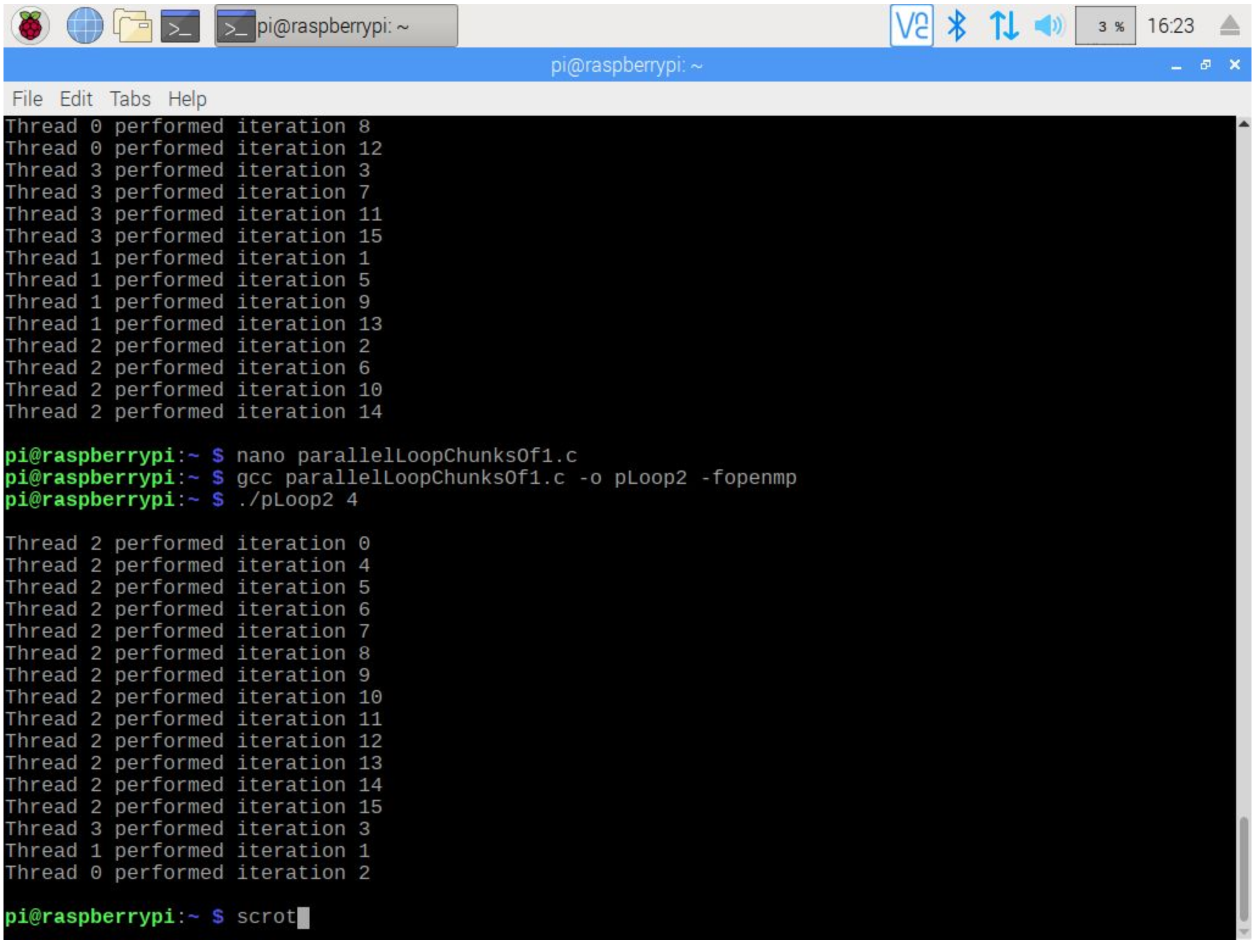
The top part shows the 16 iterations using 5 threads, as expected thread 0 does 4 iterations, the remaining threads do 3 each, as shown before in the previous images. Static scheduling is in works here.

Comparing the two loops inside the code



When the comments were removed on the second loop, both loops were run, the first loop runs statically, the second one using OpenMP's pragma parallel. Both loops performed the same static operations, they have exactly the same output. Comparing the two loops with the 'equalChunks' loop, the equal chunk loop runs the iteration in succession, meaning, thread 0 performs iteration 0,1,2,3, thread 1 performs iterations 4,5,6,7, and so on. Here, the operations are performed statically.

Dynamic scheduling

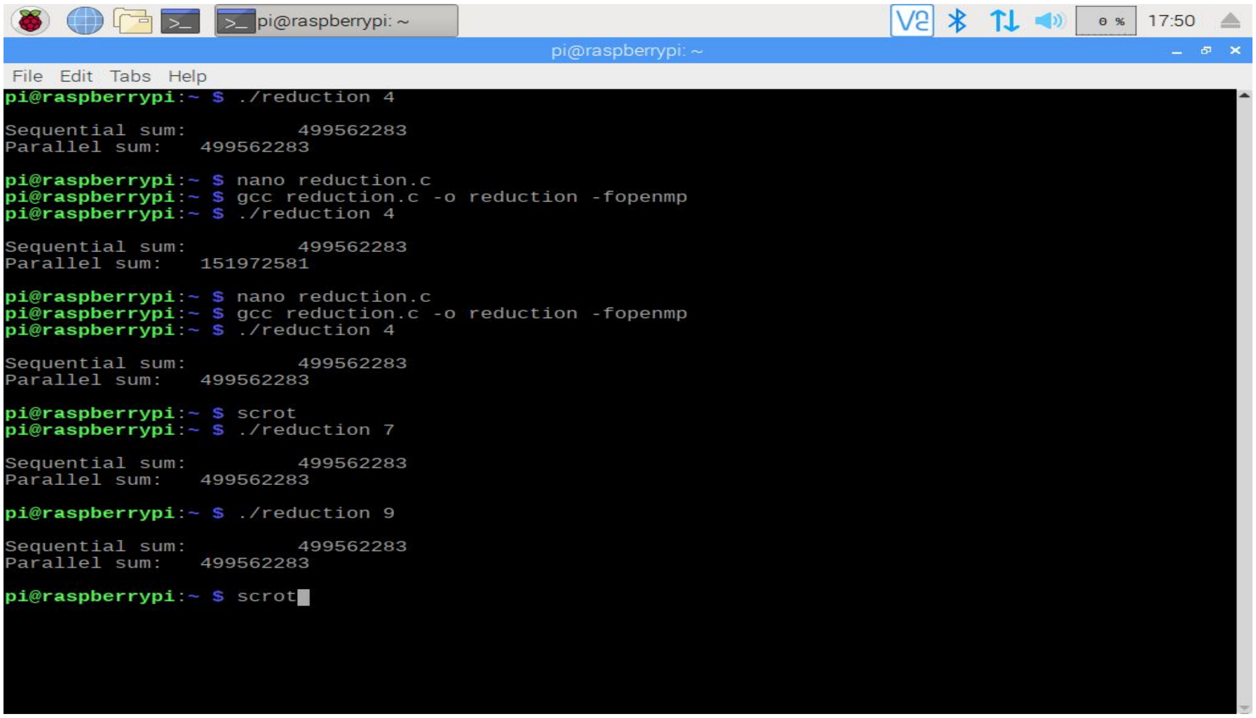


This image shows the difference between static and dynamic scheduling. We have seen how static scheduling works (top part). The bottom part uses 4 threads and the code runs dynamically. As seen, thread performs most of the iterations, in this case, 13 iterations. In dynamic scheduling, the threads are not doing the same amount of work.

Dependencies in Loops

```
#include <stdio.h> // printf()
#include <omp.h> // OpenMP
#include <stdlib.h> // rand()

void initialize(int* a, int n);
int sequentialSum(int* a, int n);
int parallelSum(int* a, int n);

#define SIZE 1000000

int main(int argc, char** argv){
int array[SIZE];

if(argc>1){
 omp_set_num_threads(atoi(argv[1]));
 }

 initialize(array, SIZE);
 printf("\nSequential sum: \t%d\nParallel sum: \t%d\n\n",
 sequentialSum(array,SIZE),
 parallelSum(array,SIZE));

 return 0;
}
/* fill array with random values */
void initialize(int* a, int n){
 int i;
 for(i=0;i<n;i++){
  a[i] = rand()%1000;
 }
}

/* sum the array sequentially */
int sequentialSum(int* a, int n){
 int sum=0;
 int i;
 for(i=0;i<n;i++){
  sum +=a[i];
 }
 return sum;
}

/* sum the array using multiple threads */
int parallelSum(int* a, int n){
 int sum=0;
 int i;
 #pragma omp parallel for reduction(+:sum)
 for(i=0;i<n;i++){
  sum +=a[i];
 }
 return sum;
}
```

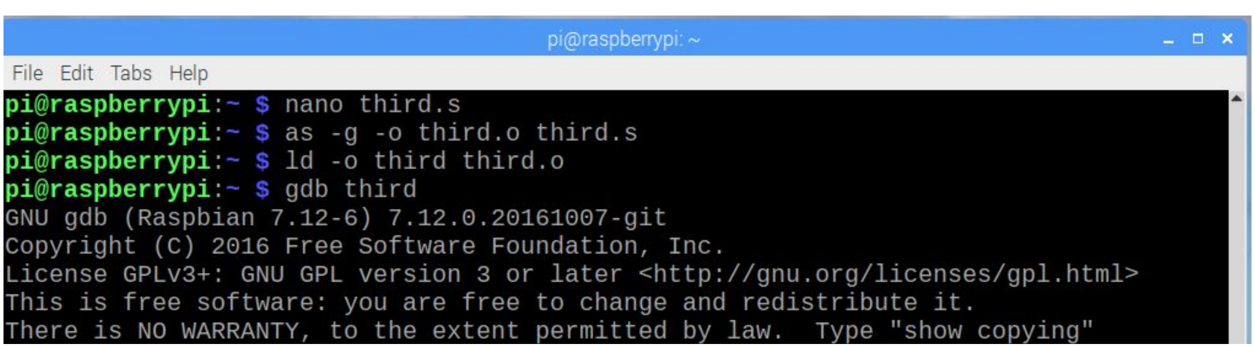
This code shows how to sequentially use the sum accumulator and its parallel computation implementation using OpenMP.



Both sequentialSum and ParallelSum results in the same output when when #pragma omp was commented out. Both have an amount of 499562283. When the #pragma omp directive was uncommented, the Parallel sum produces the wrong output 151972581. When the reduction (+:sum) was uncommented, along with the #pragma directive, the parallel method goes back to the correct sum. That shows that the sum accumulator depends on what all the threads. All threads performed their own work and sum up their work, when they are all done, the reduction clause allows the system to compute a final sum of each of the thread's sum. Using 7 and 9 threads, the output is always the same for both sequential and parallel summation.

Task 4

Part 1

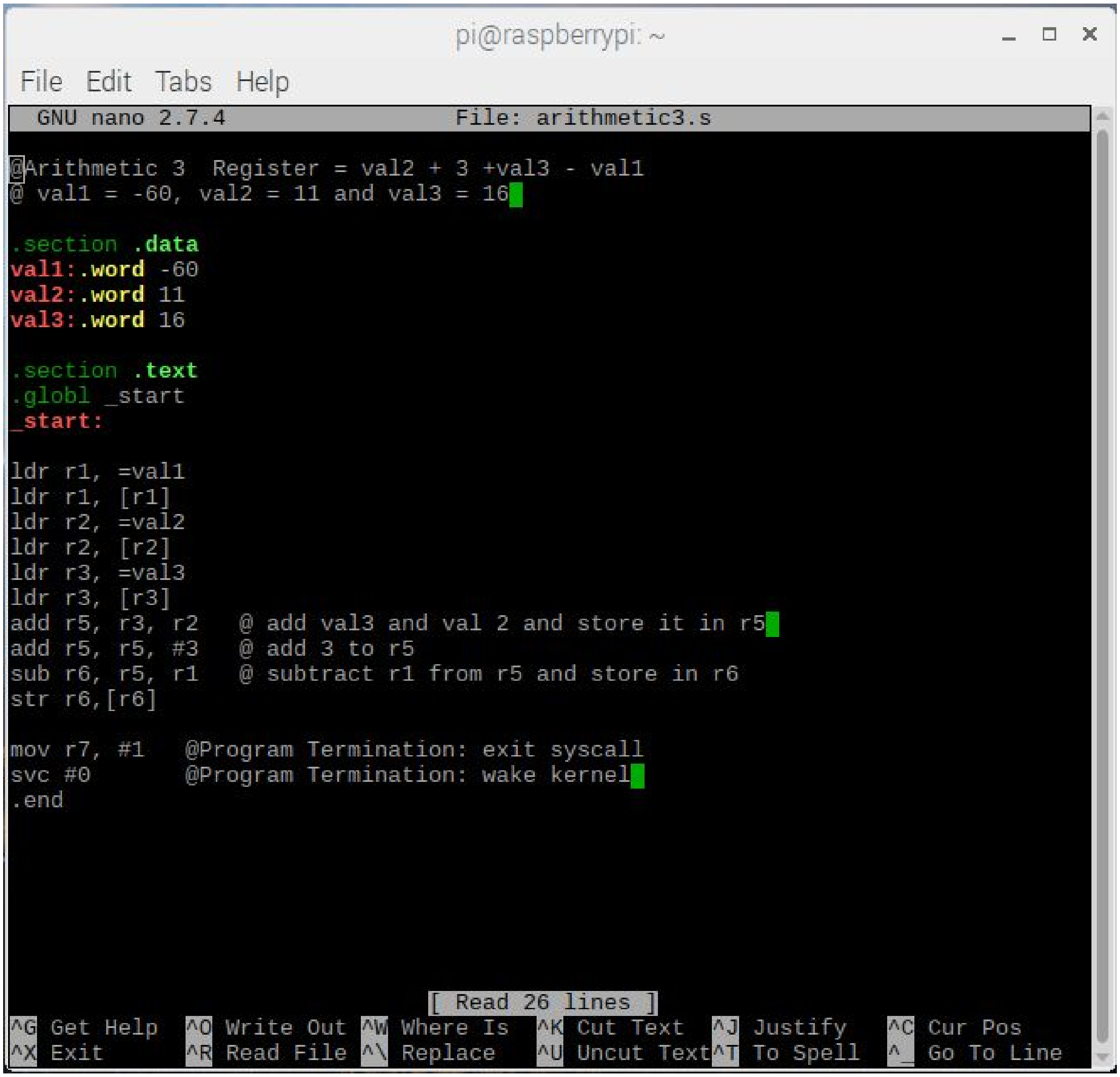


This is assembling, linking, and running with a breakpoint in the GNU Debugger after the code has been fixed. The issue it had was with declaring the signed halfword. For some reason ARM won't let us declare a signed halfword (or normal halfwords for that matter) but I noticed when you don't declare it as signed ARM still recognizes it as signed so i just declared it as an unsigned word and it worked.

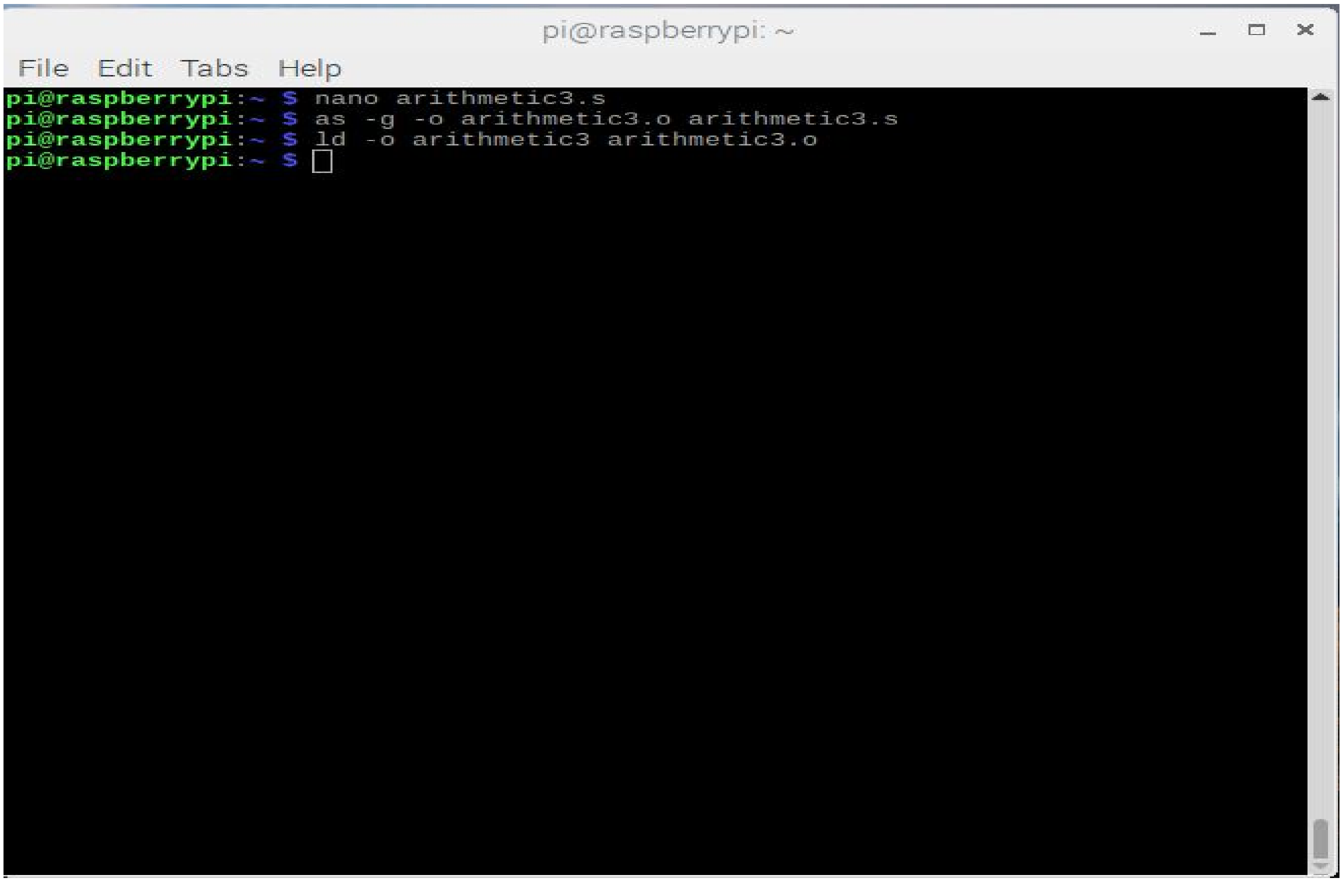
```
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.
For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from third...done.
(gdb) list 3
1               @Third program
2       .section .data
3       a: .word -2  @16-bit signed integer
4
5       .section .text
6       .globl _start
7       _start:
8
9       @ the following code attempts to load va lues into a set of registers an
d
10      @ needs debugging
(gdb) b 3
Breakpoint 1 at 0x10078: file third.s, line 3.
(gdb) x/1xh 0x10078
0x10078 <_start+4>:     0x1000
(gdb) x/1xsh 0x10078
0x10078 <_start+4>:     u"[illegible]x20ff[illegible]x3101[illegible]
(gdb) stepi
The program is not being run.
(gdb) run
Starting program: /home/pi/third

Breakpoint 1, _start () at third.s:13
13      mov r1, #0xFFFFFFFF@ = -1(signed)
```

While displaying a halfword in hexadecimal, this is what happened when I ran it with and without the s. With the s, there were some weird characters displayed that I don't recognize.

Part 2



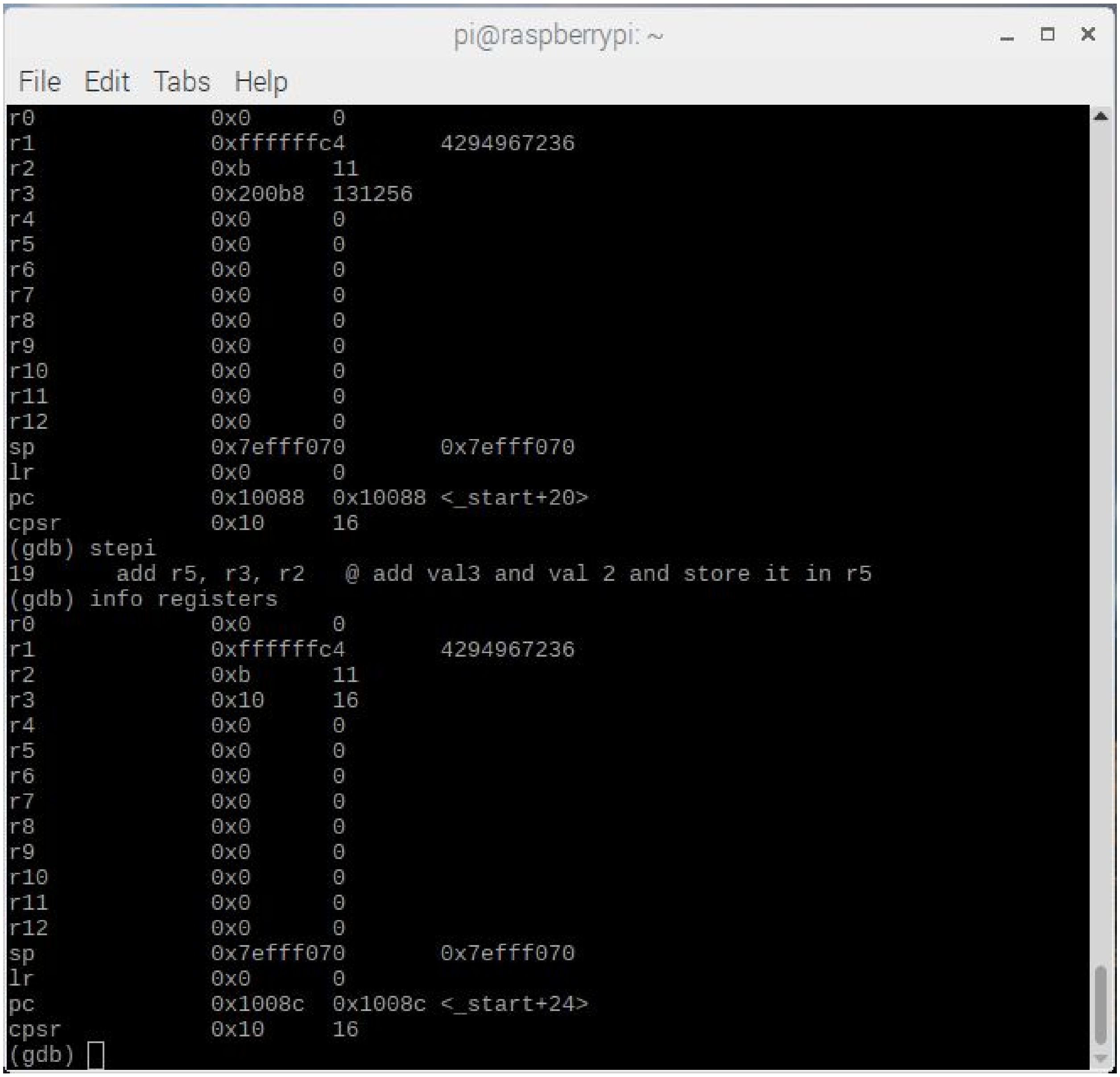
This is our code for calculating val2 + 3 + val3 - val1.



This is assembling and linking the code.

```
pi@raspberrypi: ~
File  Edit  Tabs  Help
pi@raspberrypi:~ $ ld -o arithmetic3 arithmetic3.o
pi@raspberrypi:~ $ gdb arithmetic3
GNU gdb (Raspbian 7.12-6) 7.12.0.20161007-git
Copyright (C) 2016 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-gnueabihf".
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 arithmetic3...done.
(gdb) list 17
12
13	ldr r1, =val1
14	ldr r1, [r1]
15	ldr r2, =val2
16	ldr r2, [r2]
17	ldr r3, =val3
18	ldr r3, [r3]
19	add r5, r3, r2   @ add val3 and val 2 and store it in r5
20	add r5, r5, #3   @ add 3 to r5
21	sub r6, r5, r1   @ subtract r1 from r5 and store in r6
(gdb) gdb b 10
Undefined command: "gdb".  Try "help".
(gdb)  b 10
Breakpoint 1 at 0x10078: file arithmetic3.s, line 10.
(gdb) run
Starting program: /home/pi/arithmetic3

Breakpoint 1, _start () at arithmetic3.s:14
14	ldr r1, [r1]
(gdb) 
```

This is opening up the GNU Debugger, adding a breakpoint and running the program.


pi@raspberrypi: ~

File Edit Tabs Help

```
r0             0x0      0
r1             0xffffffc4       4294967236
r2             0xb      11
r3             0x200b8  131256
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             0x7efff070       0x7efff070
lr             0x0      0
pc             0x10088  0x10088 <_start+20>
cpsr           0x10     16
(gdb) stepi
19      add r5, r3, r2   @ add val3 and val 2 and store it in r5
(gdb) info registers
r0             0x0      0
r1             0xffffffc4       4294967236
r2             0xb      11
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             0x7efff070       0x7efff070
lr             0x0      0
pc             0x1008c  0x1008c <_start+24>
cpsr           0x10     16
(gdb) 
```

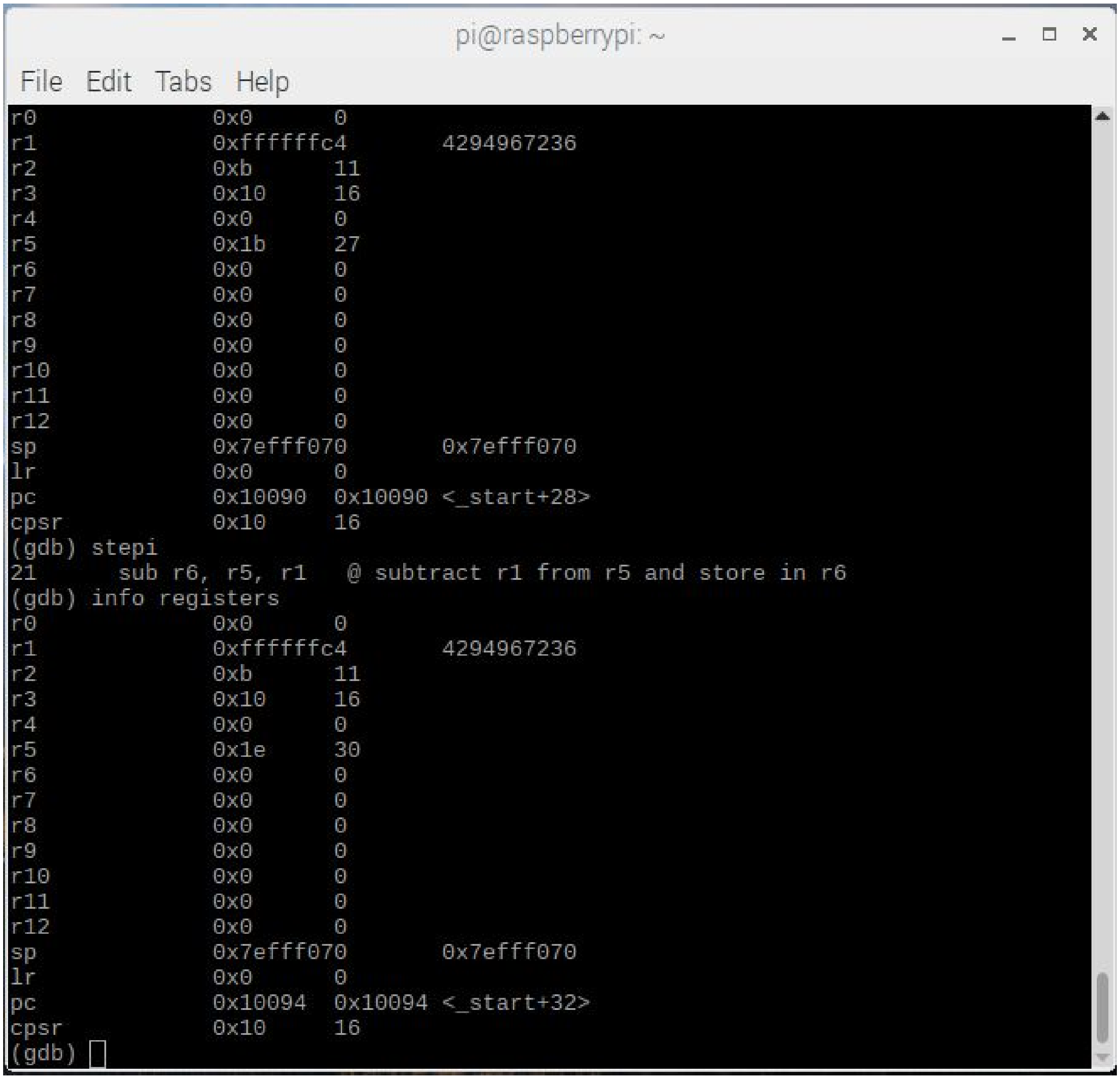
Here are the info registers after all the variables had been assigned and loaded to registers.

pi@raspberrypi: ~

File Edit Tabs Help

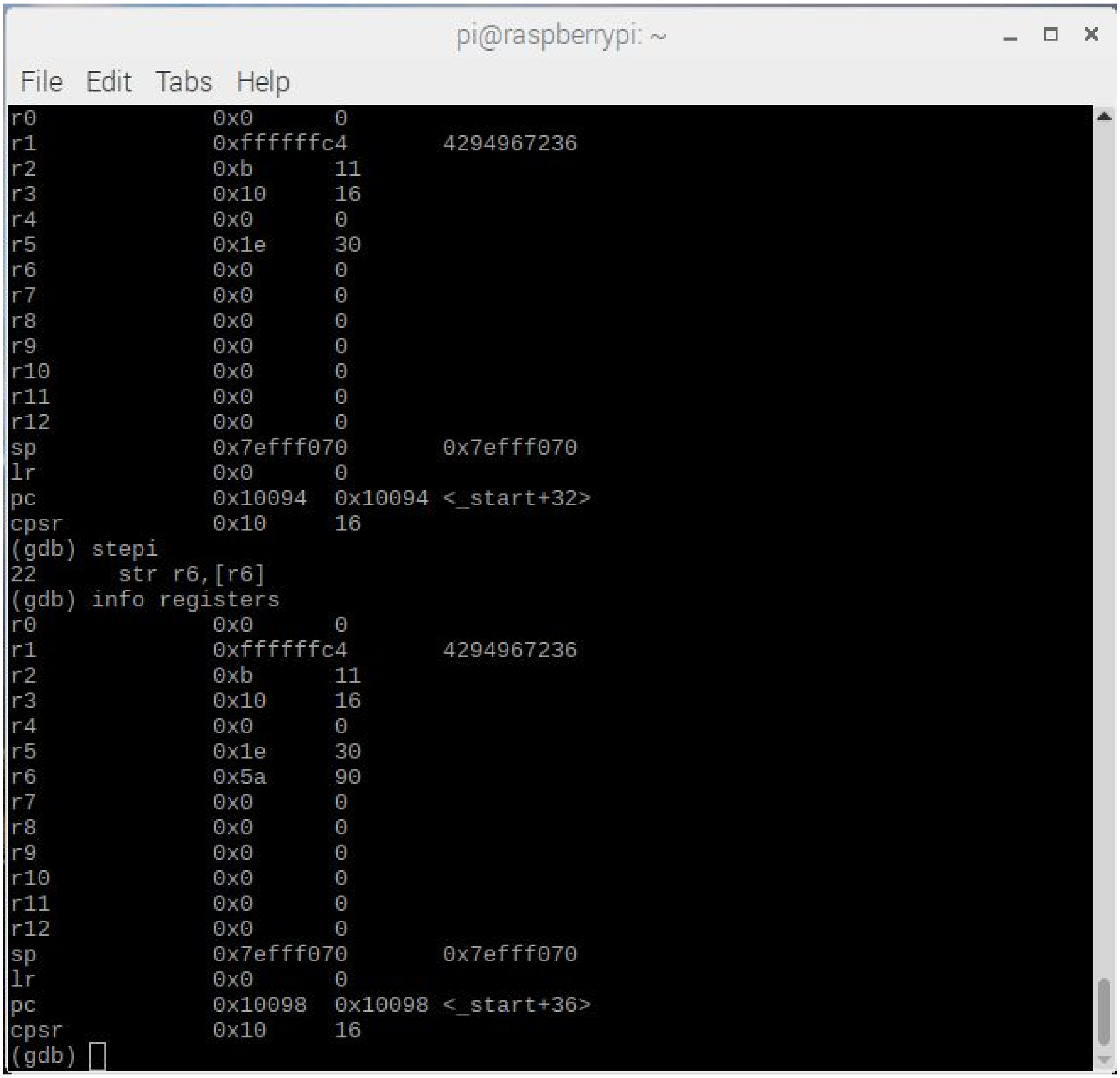
```
r0             0x0      0
r1             0xffffffc4       4294967236
r2             0xb      11
r3             0x10     16
r4             0x0      0
r5             0x0      0
r6             0x0      0
r7             0x0      0
r8             0x0      0
r9             0x0      0
r10            0x0      0
r11            0x0      0
r12            0x0      0
sp             0x7efff070       0x7efff070
lr             0x0      0
pc             0x1008c  0x1008c <_start+24>
cpsr           0x10     16
(gdb) stepi
20      add r5, r5, #3   @ add 3 to r5
(gdb) info registers
r0             0x0      0
r1             0xffffffc4       4294967236
r2             0xb      11
r3             0x10     16
r4             0x0      0
r5             0x1b     27
r6             0x0      0
r7             0x0      0
r8             0x0      0
r9             0x0      0
r10            0x0      0
r11            0x0      0
r12            0x0      0
sp             0x7efff070       0x7efff070
lr             0x0      0
pc             0x10090  0x10090 <_start+28>
cpsr           0x10     16
(gdb)
```

This is the info registers after adding val2 and val3 together and storing that in r5.



```
pi@raspberrypi: ~
File  Edit  Tabs  Help
r0             0x0      0
r1             0xffffffc4       4294967236
r2             0xb      11
r3             0x10     16
r4             0x0      0
r5             0x1b     27
r6             0x0      0
r7             0x0      0
r8             0x0      0
r9             0x0      0
r10            0x0      0
r11            0x0      0
r12            0x0      0
sp             0x7efff070       0x7efff070
lr             0x0      0
pc             0x10090  0x10090 <_start+28>
cpsr           0x10     16
(gdb) stepi
21      sub r6, r5, r1   @ subtract r1 from r5 and store in r6
(gdb) info registers
r0             0x0      0
r1             0xffffffc4       4294967236
r2             0xb      11
r3             0x10     16
r4             0x0      0
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             0x7efff070       0x7efff070
lr             0x0      0
pc             0x10094  0x10094 <_start+32>
cpsr           0x10     16
(gdb)
```

This is adding the immediate 3 to the sum of val2 and val3 which is stored in r5 and storing that in r5.



This is the registers after all the lines have been executed. I took the sum from register r5 and subtracted a negative 60 from it to get 90 which I then store in r6.

Appendix

Youtube Channel: [The Assemblers]()
Assignment Video: https://www.youtube.com/watch?v=qZHyvQ0xLJg
Slack: https://the-assemblers.slack.com/messages/CFSQ2GTDX/
Github: https://github.com/TheAssemblers