

Project #3

Multicore Computing

Problem 1

Date	Jun 13, 2020
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ENVIRONMENT

Hardware

- ☐ MacBook Pro (15-inch, 2017)
- ☐ Processor: 2.8 GHz Quad-Core Intel Core i7
- ☐ Memory: 16GB 2133 MHz LPDDR3

Operating System

- ☐ macOS Catalina, ver: 10.15.4

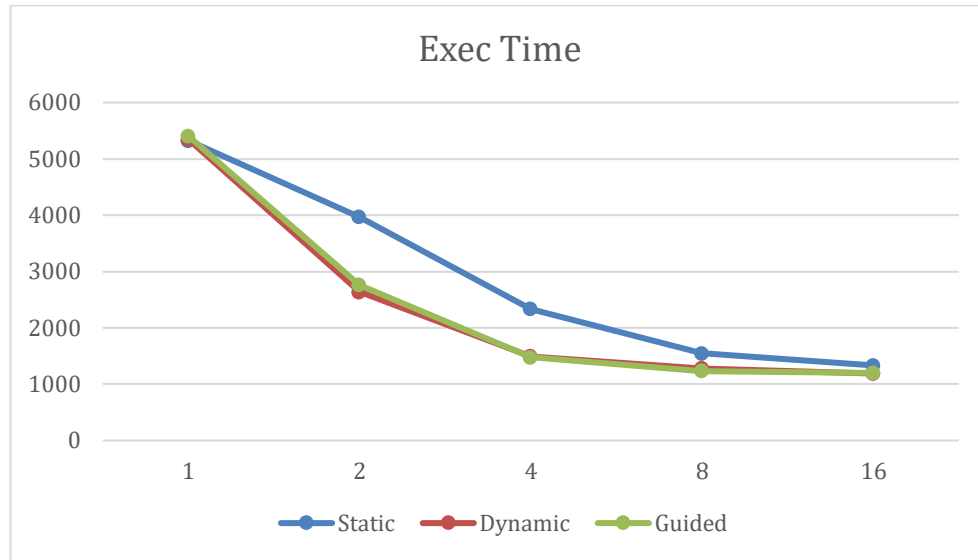
IDE (Integrated Development Environment)

- ☐ Visual Studio Code 1. 45.1
- ☐ gcc version 8.4.0 (Homebrew GCC 8.4.0_1)

Testing Environment

- ☐ iTerm2
- ☐ Build 3.3.9
- ☐ openjdk 14.0.1 2020-04-14
 - OpenJDK Runtime Environment (build 14.0.1+7)
 - OpenJDK 64-Bit Server VM (build 14.0.1+7, mixed mode, sharing)

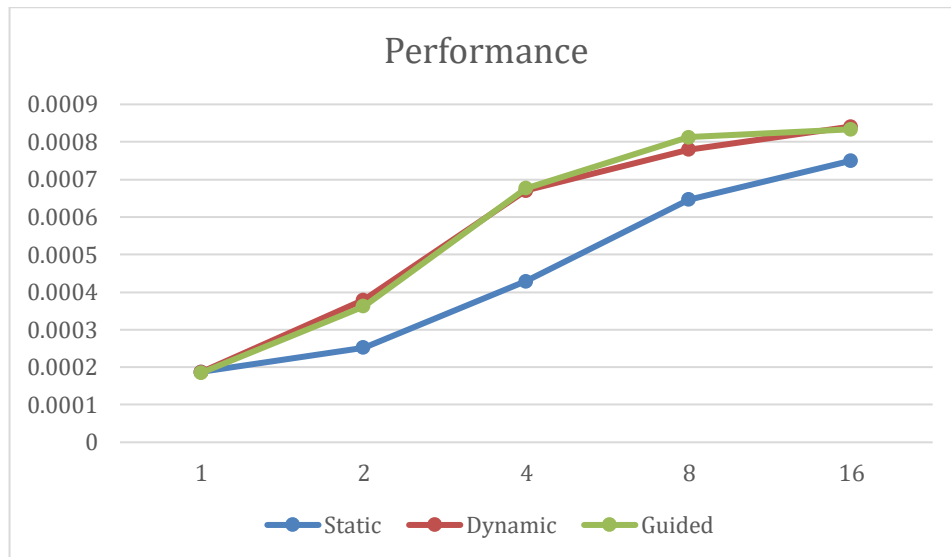
TABLE & GRAPH



▲ Fig. 1. Exec Time of multi-thread programming with static, dynamic and guided approach

Exec Time	1	2	4	8	16
Static	5325.252	3969.766	2332.277	1547.213	1332.913
Dynamic	5349.416	2634.877	1491.884	1282.083	1188.843
Guided	5405.115	2757.857	1478.695	1230.187	1199.511

▲ TABLE 1



▲ Fig. 2. Performance of multi-thread programming with static, dynamic and guided approach

Performance (1/exec time)	1	2	4	8	16
Static	0.00018778	0.0002519	0.00042877	0.00064632	0.00075024
Dynamic	0.00018694	0.00037952	0.00067029	0.00077998	0.00084115
Guided	0.00018501	0.0003626	0.00067627	0.00081288	0.00083367

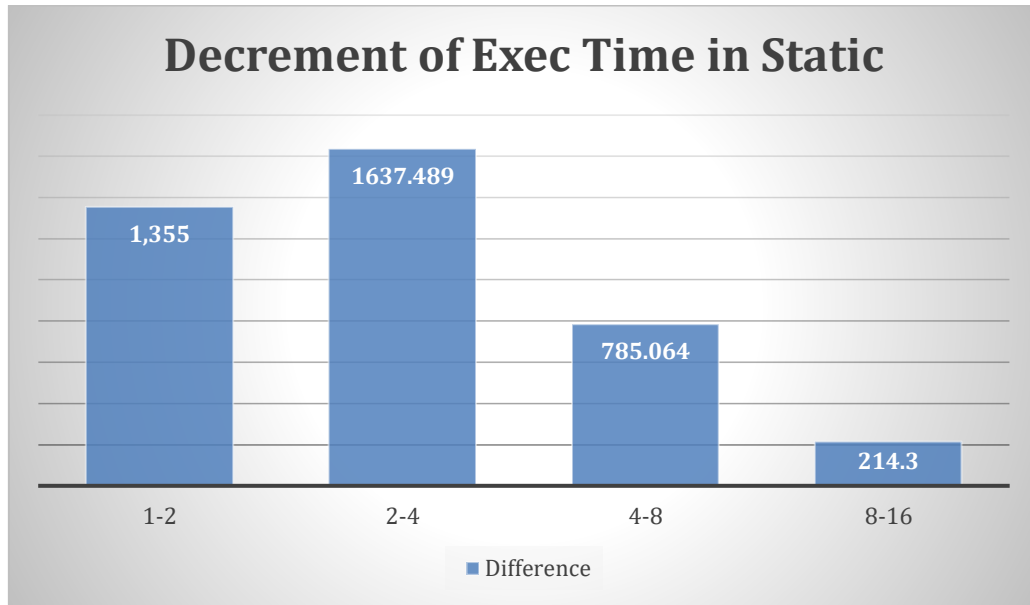
▲ TABLE 2

EXPLANATION ON RESULT

In this problem, the given work is counting the prime number. The way checking whether the number is prime or not is to divide every number under the given one.

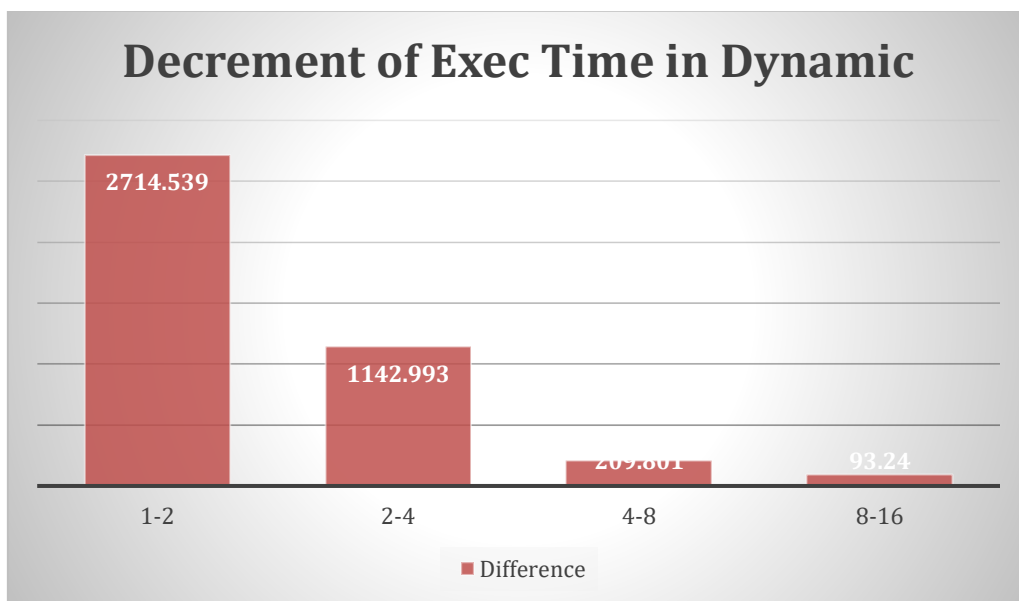
1. Exec Time

Fig. 1 shows the decrement tendency. The guided and dynamic approach tends to decrease larger than the static approach. To see the detail, I make 3 more figures.

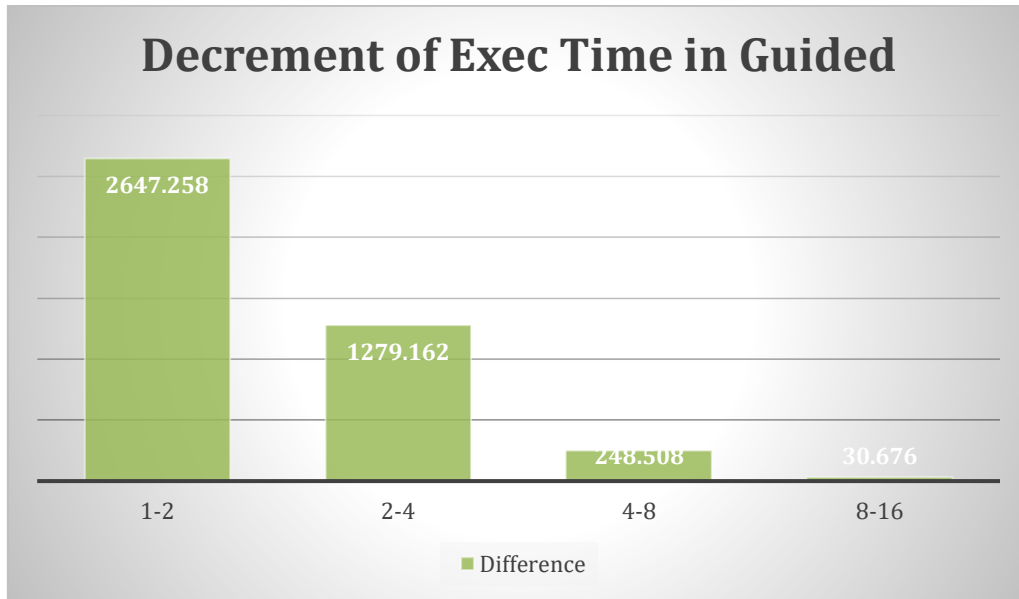


▲ Fig. 3. Decrement of execution time in the static approach

Fig. 3 shows how the execution time has decreased as the thread increases at the static load balancing approach. The task size of checking prime is greater for a big number than for a small number. In the static approach, the threads are assigned numbers in order, so the thread which receives work late is assigned more work. Thus, as the number of threads increases, the task is allocated relatively appropriately, resulting in a relatively constant reduction in execution time.

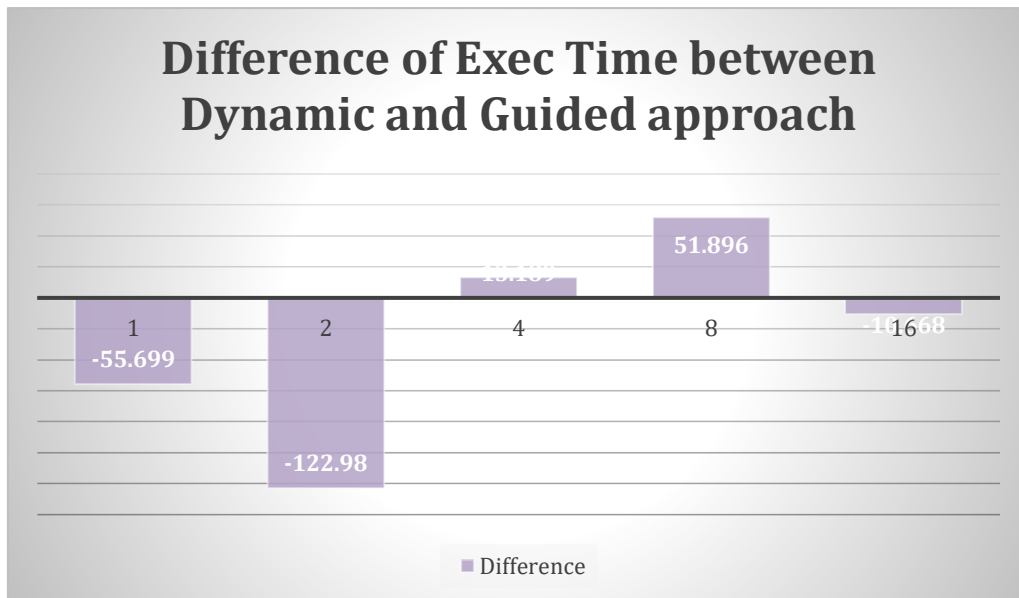


▲ Fig. 4. Decrement of execution time in the dynamic approach



▲ Fig. 5. Decrement of execution time in the guided approach

Fig. 4 and Fig. 5 shows how the execution time has decreased as the thread increases. The dynamic and guided approach gets work from the work queue. Fig4 and Fig5 show a significant reduction in run time as the initial thread increases. In addition, as the number of threads increases, the difference in execution time is reduced because of bottlenecks.



▲ Fig. 6. Difference of Exec Time between Dynamic and Guided approach

As mentioned earlier, dynamic and induced approaches use similar algorithms, so they tend to decrease execution time when increasing threads. For the guided approach, the chunk size is important. But I think the result is similar to the dynamic approach because the size is too small.

2. Performance

The performance evaluation criterion is $1/\text{exe time}$. It means that performance and exec time have an inverse relationship. Fig 2 shows that guided and dynamic approaches produce similar performance, and the output is better than the static one. The explanation of these results is fully described in exec time.

SOURCE CODE

```
// Writer: Junhyuck Woo
// Lecture: Multicore Computing
// Organization: Chung-Ang University
// Deadline: Jun 20, 2020
// Project #3
// - problem 1

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

int isPrime(int x);

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

    // Variables
    int i = 0;
    int tid = 0;
    int type = 0;
    int count = 0;
    int num_prime = 0;
    int num_thread = 0;
    double start_time, end_time;

    // Check the input argument
    if (argc != 3) {
        printf("ERROR: Wrong number of arguments\n");
        return 0;
    }

    // Check the schedule type
    type = atoi(argv[1]);
    if (type < 0 || type > 3) {
        printf("ERROR: Wrong schedule type\n");
        return 0;
    }

    // Set the thread number
    num_thread = atoi(argv[2]);
    omp_set_num_threads(num_thread);

    start_time = omp_get_wtime();
    #pragma omp parallel private(count) private(tid)
    {
        count = 0;
        tid = omp_get_thread_num();

        // Static
        if (type == 1) {
            #pragma omp for schedule(static)
            for (i = 0; i < 200000; i++) {
                if (isPrime(i)) {
                    count++;
                }
            }
        }
        // Dynamic
        else if (type == 2) {
            #pragma omp for schedule(dynamic, 4)
            for (i = 0; i < 200000; i++) {
                if (isPrime(i)) {
                    count++;
                }
            }
        }
    }

    // Guided
    else if (type == 3) {
        #pragma omp for schedule(guided, 4)
        for (i = 0; i < 200000; i++) {
            if (isPrime(i)) {
                count++;
            }
        }

        printf("%d Done: %d\n", tid, count);
        #pragma omp atomic
        num_prime += count;
    }
    /* implicit barrier */
    printf("Total: %d\n", num_prime);

    end_time = omp_get_wtime();
    printf("time elapsed: %.3lf ms\n", (end_time -
start_time)*1000);

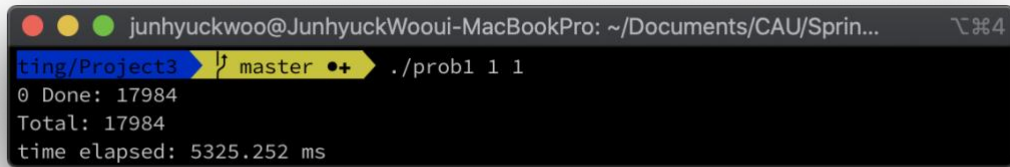
    return 0;
}

int isPrime(int x) {
    int i;
    if (x <= 1) {
        return 0;
    }
    for (i = 2; i < x; i++) {
        if ((x%i == 0) && (i != x)) {
            return 0;
        }
    }
    return 1;
}
```

OUTPUT

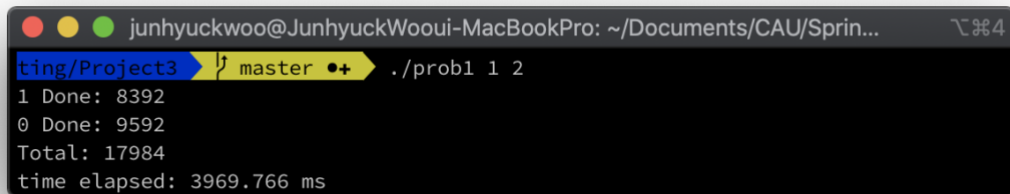
1. Static

- Thread #1

A terminal window showing the execution of a program for Thread #1. The window title is 'junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...'. The prompt is 'ting/Project3' and the command is './prob1 1 1'. The output shows '0 Done: 17984', 'Total: 17984', and 'time elapsed: 5325.252 ms'.

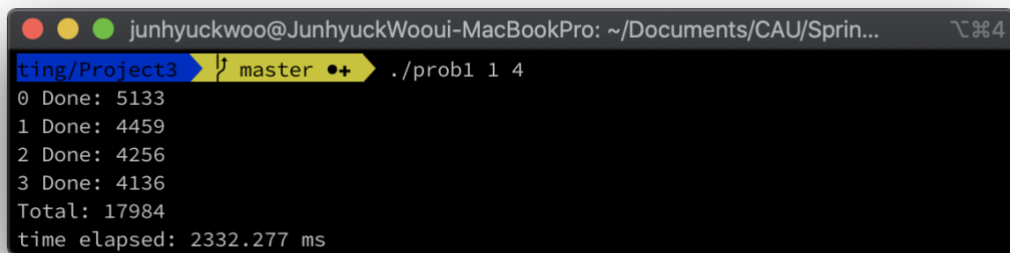
```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 1 1  
0 Done: 17984  
Total: 17984  
time elapsed: 5325.252 ms
```

- Thread #2

A terminal window showing the execution of a program for Thread #2. The window title is 'junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...'. The prompt is 'ting/Project3' and the command is './prob1 1 2'. The output shows '1 Done: 8392', '0 Done: 9592', 'Total: 17984', and 'time elapsed: 3969.766 ms'.

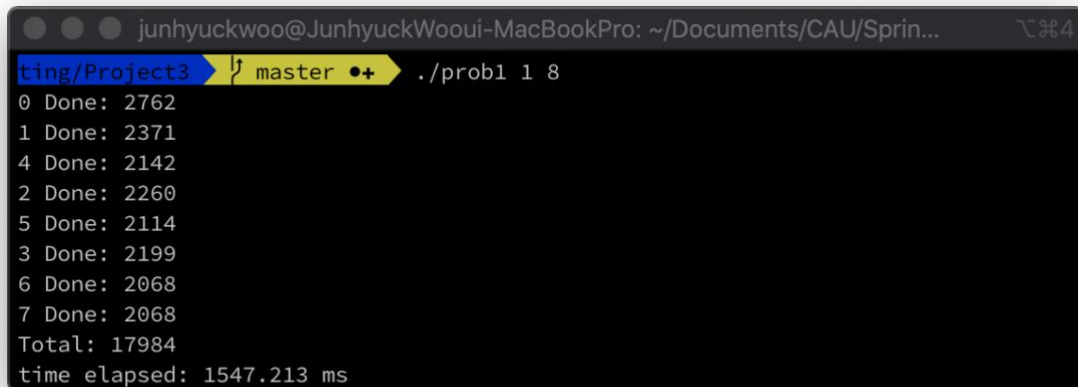
```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 1 2  
1 Done: 8392  
0 Done: 9592  
Total: 17984  
time elapsed: 3969.766 ms
```

- Thread #4

A terminal window showing the execution of a program for Thread #4. The window title is 'junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...'. The prompt is 'ting/Project3' and the command is './prob1 1 4'. The output shows '0 Done: 5133', '1 Done: 4459', '2 Done: 4256', '3 Done: 4136', 'Total: 17984', and 'time elapsed: 2332.277 ms'.

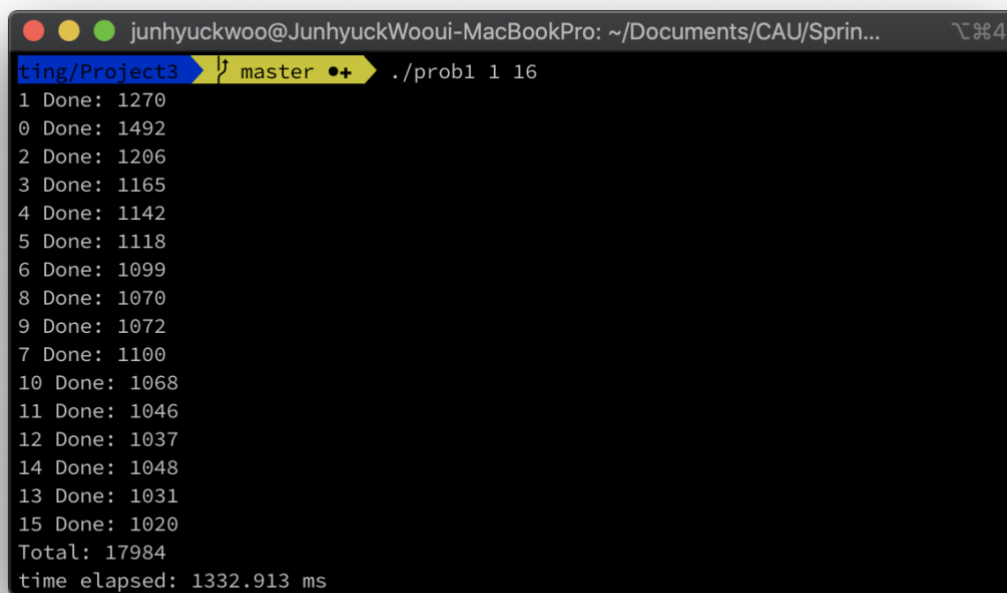
```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 1 4  
0 Done: 5133  
1 Done: 4459  
2 Done: 4256  
3 Done: 4136  
Total: 17984  
time elapsed: 2332.277 ms
```


□ Thread #8



```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 1 8  
0 Done: 2762  
1 Done: 2371  
4 Done: 2142  
2 Done: 2260  
5 Done: 2114  
3 Done: 2199  
6 Done: 2068  
7 Done: 2068  
Total: 17984  
time elapsed: 1547.213 ms
```

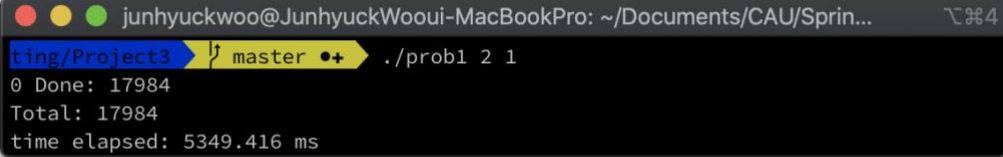
□ Thread #16



```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 1 16  
1 Done: 1270  
0 Done: 1492  
2 Done: 1206  
3 Done: 1165  
4 Done: 1142  
5 Done: 1118  
6 Done: 1099  
8 Done: 1070  
9 Done: 1072  
7 Done: 1100  
10 Done: 1068  
11 Done: 1046  
12 Done: 1037  
14 Done: 1048  
13 Done: 1031  
15 Done: 1020  
Total: 17984  
time elapsed: 1332.913 ms
```

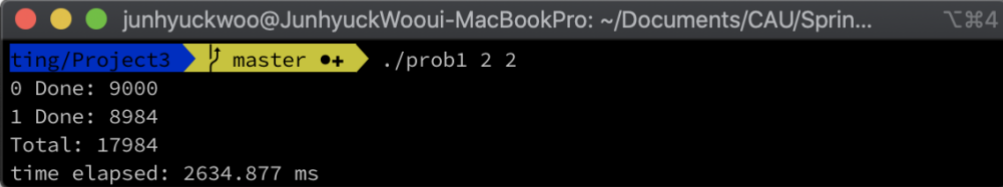
2. Dynamic

- Thread #1

A terminal window with a dark background. The title bar shows 'junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...'. The prompt is 'ting/Project3' with a blue arrow icon. The command is 'master •+ ./prob1 2 1'. The output shows '0 Done: 17984', 'Total: 17984', and 'time elapsed: 5349.416 ms'.

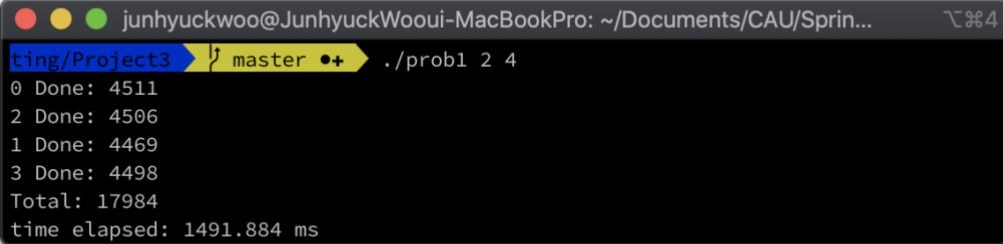
```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master •+ ./prob1 2 1  
0 Done: 17984  
Total: 17984  
time elapsed: 5349.416 ms
```

- Thread #2

A terminal window with a dark background. The title bar shows 'junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...'. The prompt is 'ting/Project3' with a blue arrow icon. The command is 'master •+ ./prob1 2 2'. The output shows '0 Done: 9000', '1 Done: 8984', 'Total: 17984', and 'time elapsed: 2634.877 ms'.

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master •+ ./prob1 2 2  
0 Done: 9000  
1 Done: 8984  
Total: 17984  
time elapsed: 2634.877 ms
```

- Thread #4

A terminal window with a dark background. The title bar shows 'junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...'. The prompt is 'ting/Project3' with a blue arrow icon. The command is 'master •+ ./prob1 2 4'. The output shows '0 Done: 4511', '2 Done: 4506', '1 Done: 4469', '3 Done: 4498', 'Total: 17984', and 'time elapsed: 1491.884 ms'.

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master •+ ./prob1 2 4  
0 Done: 4511  
2 Done: 4506  
1 Done: 4469  
3 Done: 4498  
Total: 17984  
time elapsed: 1491.884 ms
```

□ Thread #8

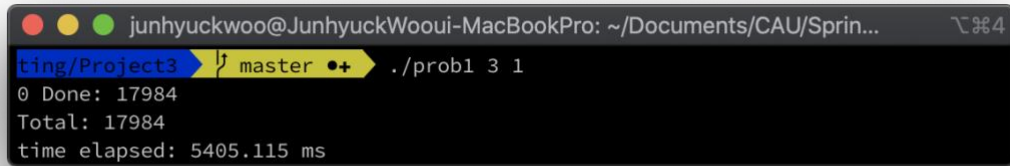
```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...
ting/Project3 master ➤ ./prob1 2 8
6 Done: 2313
7 Done: 2180
3 Done: 2322
1 Done: 2313
2 Done: 2179
0 Done: 2106
4 Done: 2289
5 Done: 2282
Total: 17984
time elapsed: 1282.083 ms
```

□ Thread #16

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...
12 Done: 1037
2 Done: 1038
15 Done: 973
7 Done: 1257
1 Done: 1225
14 Done: 1268
11 Done: 1045
0 Done: 1029
3 Done: 1222
6 Done: 1215
5 Done: 1130
4 Done: 1223
10 Done: 1032
13 Done: 1033
8 Done: 1231
Total: 17984
time elapsed: 1188.843 ms
junhyuckwoo ~/Documents/CAU/Spring|2020/Multicore_Computing/CAU-MulticoeCompu
ting/Project3 master ➤
```

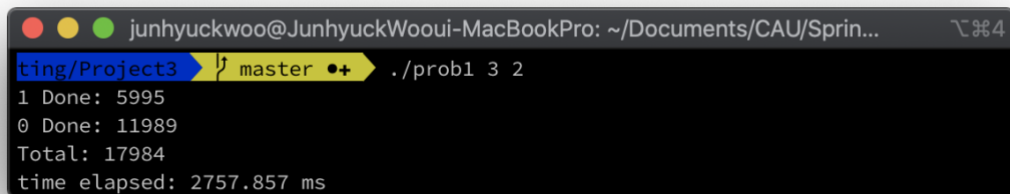
3. Guided

- Thread #1

A terminal window showing the execution of a program. The prompt is 'ting/Project3' and the command is './prob1 3 1'. The output shows '0 Done: 17984', 'Total: 17984', and 'time elapsed: 5405.115 ms'.

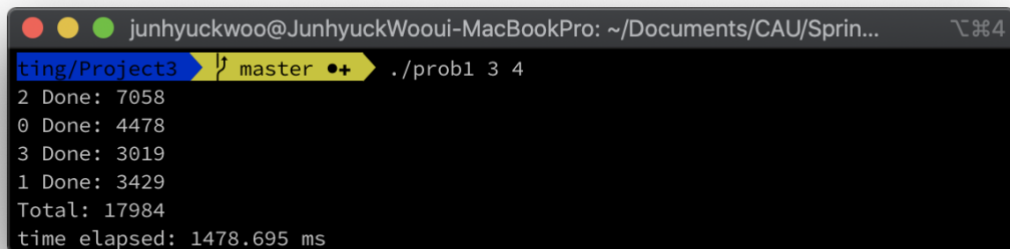
```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 3 1  
0 Done: 17984  
Total: 17984  
time elapsed: 5405.115 ms
```

- Thread #2

A terminal window showing the execution of a program. The prompt is 'ting/Project3' and the command is './prob1 3 2'. The output shows '1 Done: 5995', '0 Done: 11989', 'Total: 17984', and 'time elapsed: 2757.857 ms'.

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 3 2  
1 Done: 5995  
0 Done: 11989  
Total: 17984  
time elapsed: 2757.857 ms
```

- Thread #4

A terminal window showing the execution of a program. The prompt is 'ting/Project3' and the command is './prob1 3 4'. The output shows '2 Done: 7058', '0 Done: 4478', '3 Done: 3019', '1 Done: 3429', 'Total: 17984', and 'time elapsed: 1478.695 ms'.

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin...  
ting/Project3 master ➤ ./prob1 3 4  
2 Done: 7058  
0 Done: 4478  
3 Done: 3019  
1 Done: 3429  
Total: 17984  
time elapsed: 1478.695 ms
```

□ Thread #8

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin... ㄿ⌘4
4 Done: 3956
5 Done: 1835
0 Done: 1674
7 Done: 1455
3 Done: 2477
6 Done: 1580
2 Done: 2029
Total: 17984
time elapsed: 1230.187 ms
junhyuckwoo ~/Documents/CAU/Spring|2020/Multicore_Computing/CAU-MulticoeCompu
ting/Project3 master •+
```

□ Thread #16

```
junhyuckwoo@JunhyuckWooui-MacBookPro: ~/Documents/CAU/Sprin... ㄿ⌘4
4 Done: 1759
6 Done: 1549
1 Done: 1276
5 Done: 1401
10 Done: 896
14 Done: 732
2 Done: 2144
13 Done: 792
15 Done: 753
12 Done: 806
8 Done: 1008
11 Done: 844
9 Done: 1101
3 Done: 956
0 Done: 772
Total: 17984
time elapsed: 1199.511 ms
junhyuckwoo ~/Documents/CAU/Spring|2020/Multicore_Computing/CAU-MulticoeCompu
ting/Project3 master •+
```