

Introduction

I completed project 1 on a virtual machine running on macOSX. To test my programs, I used five text files that I found on the internet [1].

- Test1.txt: 769 KBs of words.
- Test2.txt: 611 KBs of words.
- Test3.txt: 125 KBs of words.
- Test4.txt: 4 MBs of words.
- Test5.txt: 2,2 MBs of words.

First, I run both of my programs on the test1.txt. Next, incremented child/thread count by one and loaded the test2.txt file. I continued this pattern until I created five children/threads, with each running the respective test file. I measured the amount of time it took to create children/threads. Moreover, I recorded the time it takes for both programs to process text files. Lastly, I saved the time of the algorithm to merge sorted words in each program while printing the total execution time for both programs with respective child/thread count.

To interpret my experiment results, I will give a recording of my terminal output. Next, plot the results on a graph for interpretation.

Terminal Outputs

- Thread count vs children count

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc textfiles/test1.txt
Thread created with id: 0
Thread creation time:
    In seconds: 0
    In microseconds: 75
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 11
    In microseconds: 10897057
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 8287
Program run for:
    In seconds: 11
    In microseconds: 10920547
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

twc execution time with 1 thread

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc textfiles/test1.txt
args count: 2
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 128
Waiting child: 0
Processes finished processing in time:
    In seconds: 11
    In microseconds: 11156985
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 2999245
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 14
    In microseconds: 14158993
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

pwc execution with 1 child

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc textfiles/test1.txt textfiles/t
est2.txt
Thread created with id: 0
Thread created with id: 1
Thread creation time:
    In seconds: 0
    In microseconds: 107
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 17
    In microseconds: 16953523
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 11936
Program run for:
    In seconds: 17
    In microseconds: 16980215
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

twc execution time with 2 threads

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc textfiles/test1.txt textfiles/t
est2.txt
args count: 3
Child with id: 0 is created.
Child with id: 1 is created.
Process creation time:
    In seconds: 0
    In microseconds: 161
Waiting child: 0
Waiting child: 1
Processes finished processing in time:
    In seconds: 17
    In microseconds: 17479114
Error on reading child: 0, queue is empty!
Error on reading child: 1, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 3005149
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 20
    In microseconds: 20487750
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

pwc execution time with 2 children

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc textfiles/test1.txt textfiles/t
est2.txt textfiles/test3.txt
Thread created with id: 0
Thread created with id: 1
Thread created with id: 2
Thread creation time:
    In seconds: 0
    In microseconds: 442
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 17
    In microseconds: 16531250
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 26238
Program run for:
    In seconds: 17
    In microseconds: 16580071
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

twc execution time with 3 threads

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc textfiles/test1.txt textfiles/t
est2.txt textfiles/test3.txt
args count: 4
Child with id: 0 is created.
Child with id: 1 is created.
Child with id: 2 is created.
Process creation time:
    In seconds: 0
    In microseconds: 236
Waiting child: 0
Waiting child: 1
Waiting child: 2
Processes finished processing in time:
    In seconds: 18
    In microseconds: 17520199
Error on reading child: 0, queue is empty!
Error on reading child: 2, queue is empty!
Error on reading child: 1, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 3006944
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 21
    In microseconds: 20532548
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc textfiles/test1.txt textfiles/t
```

pwc execution time with 3 children

```

cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 183
Waiting child: 0
Processes finished processing in time:
    In seconds: 1
    In microseconds: 829341
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 2996184
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 4
    In microseconds: 3834031
cevat@cevat-VirtualBox:~/Desktop/Project1$
    In seconds: 56
    In microseconds: 56443801
cevat@cevat-VirtualBox:~/Desktop/Project1$

```

Caption

twc execution time with 4 threads

```

cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc textfiles/test1.txt textfiles/t
est2.txt textfiles/test3.txt textfiles/test4.txt
args count: 5
Child with id: 0 is created.
Child with id: 1 is created.
Child with id: 2 is created.
Child with id: 3 is created.
Process creation time:
    In seconds: 0
    In microseconds: 311
Waiting child: 0
Waiting child: 1
Waiting child: 2
Waiting child: 3
Processes finished processing in time:
    In seconds: 51
    In microseconds: 51160005
Error on reading child: 3, queue is empty!
Error on reading child: 0, queue is empty!
Error on reading child: 2, queue is empty!
Error on reading child: 1, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 3002602
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 54
    In microseconds: 54169175
cevat@cevat-VirtualBox:~/Desktop/Project1$

```

pwc execution time with 4 children

```

cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc textfiles/test1.txt textfiles/t
est2.txt textfiles/test3.txt textfiles/test4.txt textfiles/test5.txt
Thread created with id: 0
Thread created with id: 1
Thread created with id: 2
Thread created with id: 3
Thread created with id: 4
Thread creation time:
    In seconds: 0
    In microseconds: 418
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 50
    In microseconds: 49775575
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 59322
Program run for:
    In seconds: 50
    In microseconds: 49853768
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc textfiles/test1.txt textfiles/t

```

twc execution time with 5 threads

```

cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc textfiles/test1.txt textfiles/t
est2.txt textfiles/test3.txt textfiles/test4.txt textfiles/test5.txt
args count: 6
Child with id: 0 is created.
Child with id: 1 is created.
Child with id: 2 is created.
Child with id: 3 is created.
Child with id: 4 is created.
Process creation time:
    In seconds: 0
    In microseconds: 315
Waiting child: 0
Waiting child: 1
Waiting child: 2
Waiting child: 3
Waiting child: 4
Processes finished processing in time:
    In seconds: 50
    In microseconds: 50432473
Error on reading child: 4, queue is empty!
Error on reading child: 3, queue is empty!
Error on reading child: 0, queue is empty!
Error on reading child: 2, queue is empty!
Error on reading child: 1, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 3044878
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 53
    In microseconds: 53482643
cevat@cevat-VirtualBox:~/Desktop/Project1$

```

pwc execution time with 5 children

- Thread vs child process performance on text file size

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc 1 textfiles/test0.txt
Thread created with id: 0
Thread creation time:
    In seconds: 0
    In microseconds: 115
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 1
    In microseconds: 547018
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 5780
Program run for:
    In seconds: 1
    In microseconds: 556356
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

twc on processing 125 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 183
Waiting child: 0
Processes finished processing in time:
    In seconds: 1
    In microseconds: 829341
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 2996184
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 4
    In microseconds: 3834031
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

pwc on processing 125 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc 1 textfiles/test0.txt
Thread created with id: 0
Thread creation time:
    In seconds: 0
    In microseconds: 288
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 10
    In microseconds: 10641327
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 17930
Program run for:
    In seconds: 10
    In microseconds: 10665377
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

twc on processing 726 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 123
Waiting child: 0
Processes finished processing in time:
    In seconds: 11
    In microseconds: 11017348
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 2998768
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 14
    In microseconds: 14019171
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

pwc on processing 726 KBs.


```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc 1 textfiles/test0.txt
Thread created with id: 0
Thread creation time:
    In seconds: 0
    In microseconds: 156
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 26
    In microseconds: 25540971
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 28534
Program run for:
    In seconds: 26
    In microseconds: 25582670
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
```

twc on processing 1595 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 153
Waiting child: 0
Processes finished processing in time:
    In seconds: 23
    In microseconds: 23312910
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 2998861
All message queues are empty. Output file generated. Parent process has finished
..
Program run time:
    In seconds: 26
    In microseconds: 26314862
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc 1 textfiles/test0.txt
```

pwc on processing 1595 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc 1 textfiles/test0.txt
Thread created with id: 0
Thread creation time:
    In seconds: 0
    In microseconds: 78
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 172
    In microseconds: 171978014
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 21897
Program run for:
    In seconds: 172
    In microseconds: 172008856
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

twc on processing 3795 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 514
Waiting child: 0
Processes finished processing in time:
    In seconds: 184
    In microseconds: 184238308
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 2999165
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 187
    In microseconds: 187240876
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

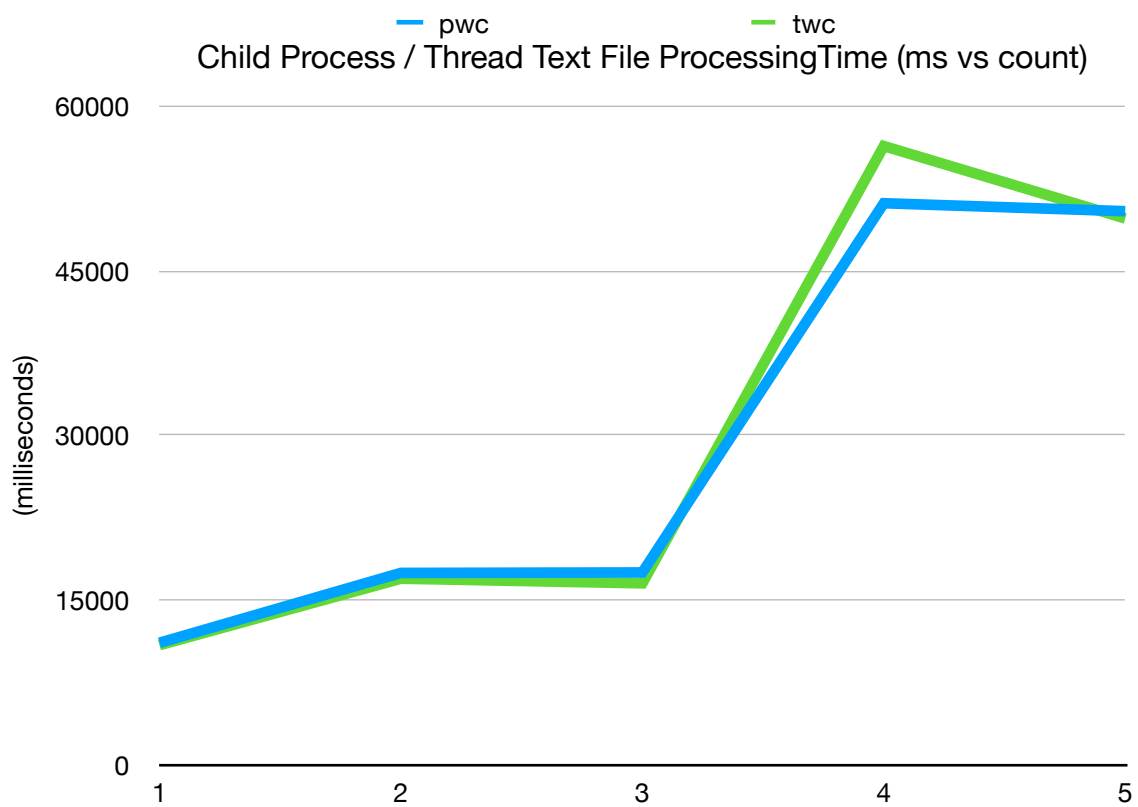
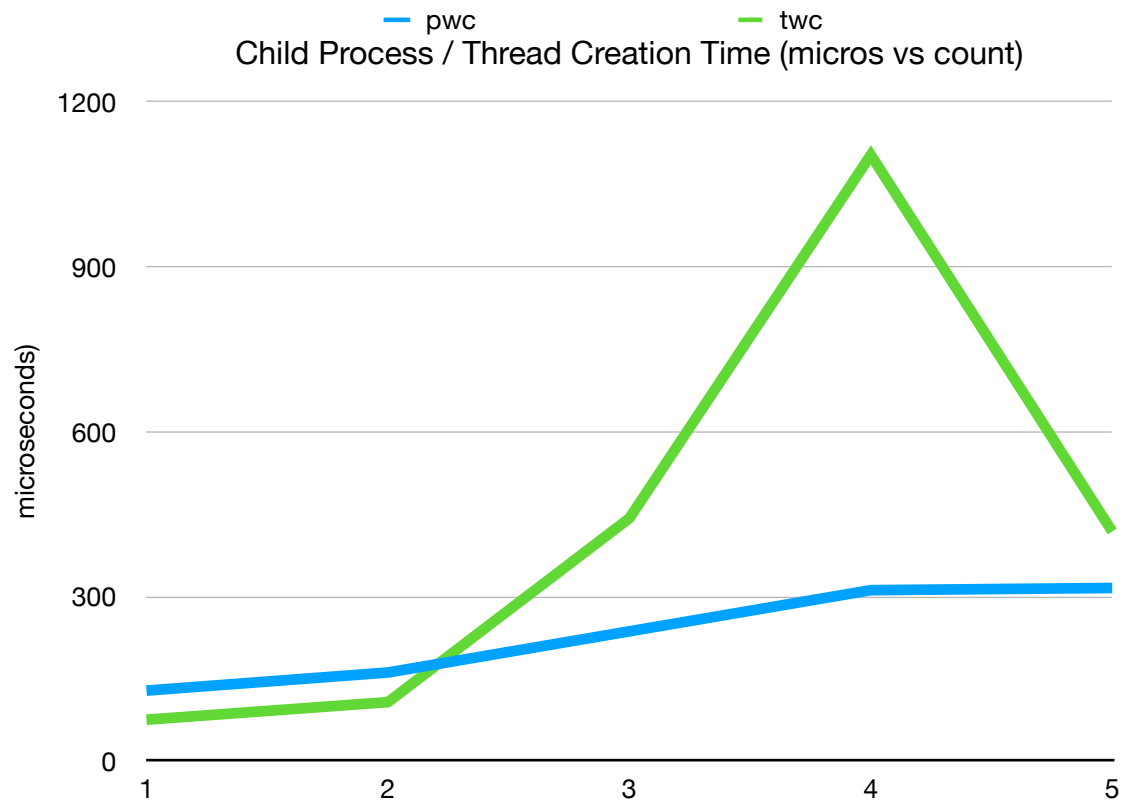
pwc on processing 3795 KBs.

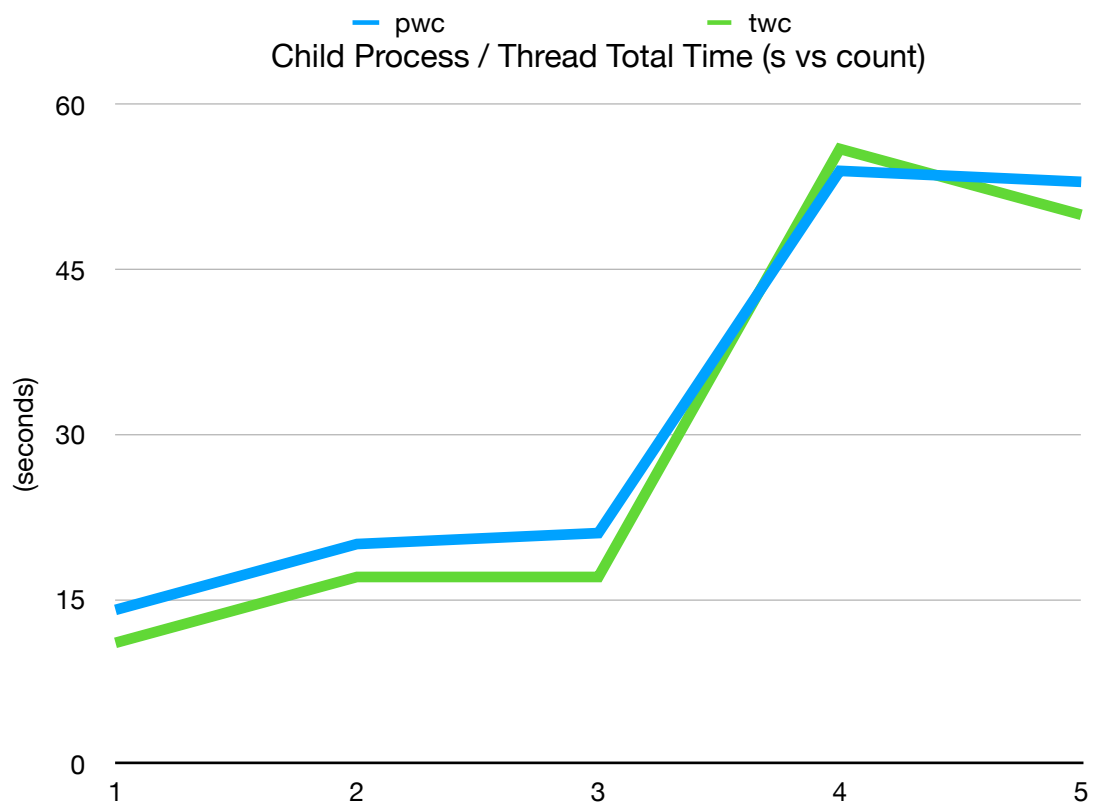
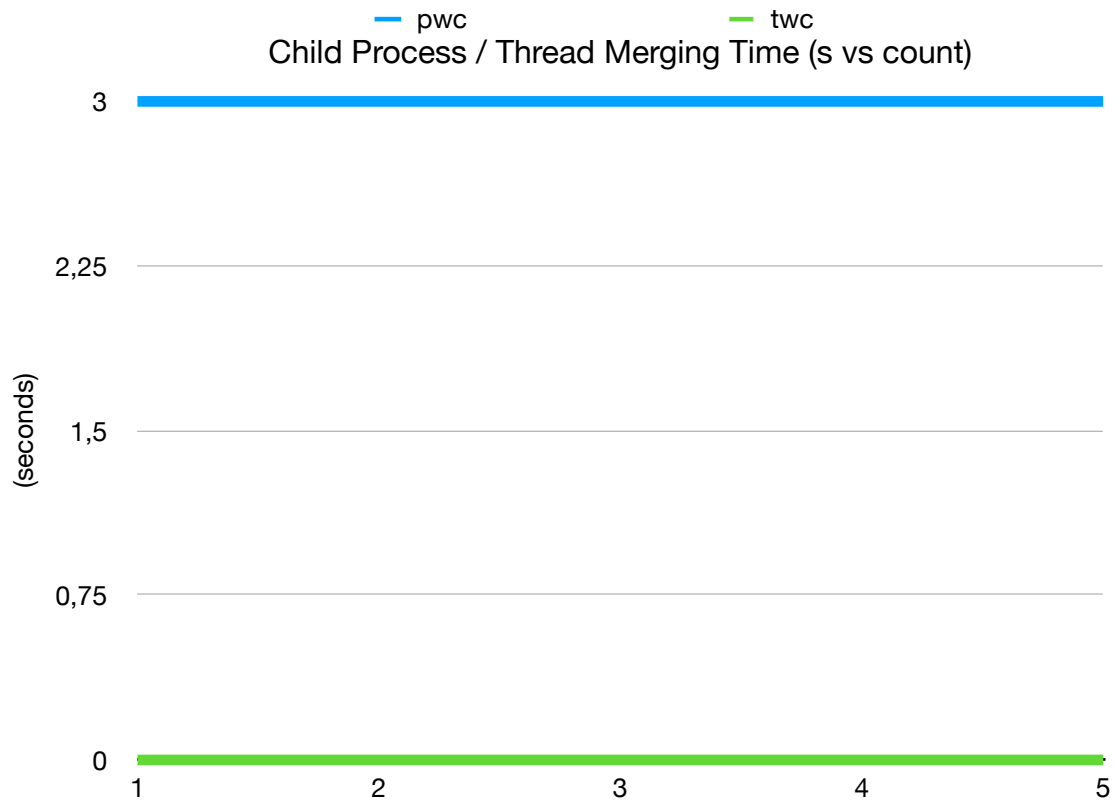
```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./twc 1 textfiles/test0.txt
Thread created with id: 0
Thread creation time:
    In seconds: 0
    In microseconds: 75
Waiting for threads...
Threads completed...
Threads completed their tasks in time:
    In seconds: 285
    In microseconds: 285127523
Algorithm completed for threads:
    In seconds: 0
    In microseconds: 39392
Program run for:
    In seconds: 285
    In microseconds: 285186303
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

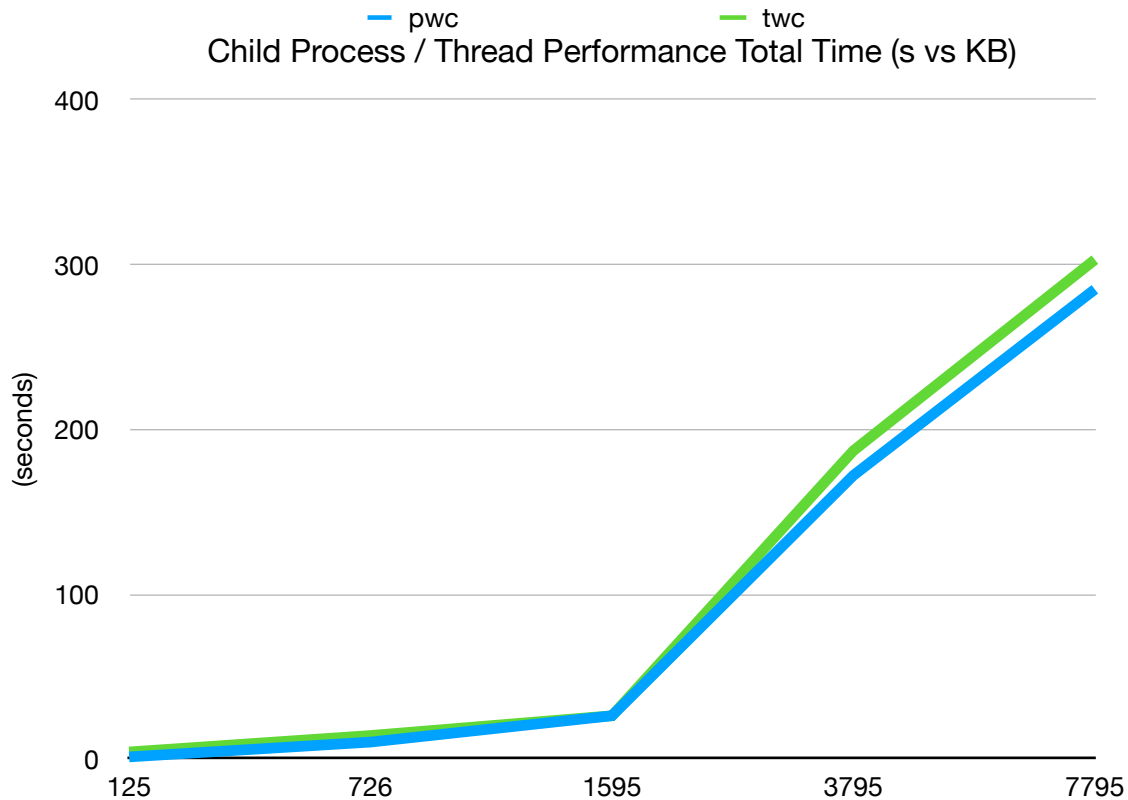
twc on processing 7795 KBs.

```
cevat@cevat-VirtualBox:~/Desktop/Project1$ ./pwc 1 textfiles/test0.txt
Child with id: 0 is created.
Process creation time:
    In seconds: 0
    In microseconds: 99
Waiting child: 0
Processes finished processing in time:
    In seconds: 300
    In microseconds: 300167449
Error on reading child: 0, queue is empty!
Process merge algorithm end time:
    In seconds: 3
    In microseconds: 3002928
All message queues are empty. Output file generated. Parent process has finished.
..
Program run time:
    In seconds: 303
    In microseconds: 303172670
cevat@cevat-VirtualBox:~/Desktop/Project1$
```

pwc on processing 7795 KBs.

Graphs for thread count vs children count



Graph for thread performance vs child performance on file size**Interpretation**

Creating a thread is generally faster than creating processes. Although the plot displays that as the number of threads increase, the time it requires to create threads is slower than creating processes. When I experimented later to see if this is actually true. I found that thread creation time for 5 text files was faster by 20 microseconds compared to process creation. The reason why in my experiment the thread creation suddenly jumped to a high value could be related to Kernel running system programs. In theory, threads only need a stack within the program space. Therefore, I was not surprised to see that thread creation is usually faster compared to processes.

Threads and child processes performed similarly when processing text files to create sorted linked lists. Furthermore, their total run time is similar too. Nevertheless, one interesting observation is that pwc is slower by three seconds compared to twc when merging sorted linked lists. I believe the reason is that since the parent process and child process has to communicate using a message queue, first, the message is sent to the queue by the syscall. Here, Kernel takes control and puts the message. Next, parent makes an another syscall to read this message. As a result, Kernel runs to provide parent with the message. However, in twc, as the created threads and main thread share the

same memory space, the main thread can easily access the sorted linked lists generated by the created threads. This means that, the program does not have to switch mode to perform message transfer. This is the reason why there is a strict three seconds difference between twc and pwc. Kernel syscalls slows down the pwc program.

I did not expect to see process performance being so close to threads in general. This is because, I am using a quad-core computer. Threading can benefit from the cores while running in the CPU but processes has to wait to be put in the CPU. This means that, while threading can use cores for parallelization, processes can only be concurrent with respect to each other. As a result, threading in a process using multiple cores could be faster than multiple processes running concurrently on the CPU. Although there is not a significant difference, in general, threading performs better.

I would argue that, processes are an excellent way of creating individual programs within a program where the parent does not depend on the children. However, if children are not handled properly, there is a risk of a child becoming a zombie process which I experienced in my project. Furthermore, threading is a brilliant way to divide and conquer problems that have high communication traffic.

References

[1] “The Canterbury Corpus,” *corpus*, [Online]. Available: <https://corpus.canterbury.ac.nz/descriptions/>. [Accessed: 17.10.2020].