DUE DATE: **By the deadline specified on Canvas**

CSE-443/543: High Performance Computing

Exercise #6

Max Points: 20

You should save/rename this document using the naming convention MUid_ex6.docx (example: `raodm_ex6.docx`).

Objective: The objective of this exercise is to:

- Understand the statistics reported by `/usr/bin/time`

Fill in answers to all of the questions. For almost all the questions you can simply copy-paste appropriate text from the shell/output window into this document. You may discuss the questions with your instructor.

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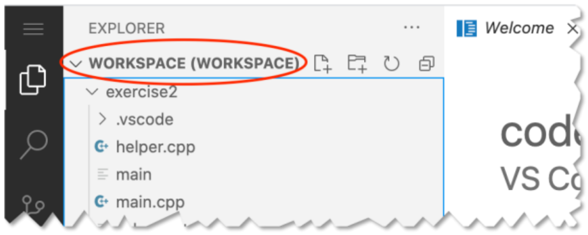
Part #1: Setting up the exercise on OSC

Estimated time: < 10 minutes

Exercise

1. Log into OSC's OnDemand portal via https://ondemand.osc.edu/. Login with your OSC id and password.



2. Startup a VS-Code server and connect to VS-Code. Ensure you switch to your workspace. Your VS-Code window should appear as shown in the adjacent screenshot.

3. Next, create a new VS-Code project in the following manner:
   a. Start a new terminal in VS-Code
   b. In the VS-Code terminal use the following commands:

```
$ # First change to your workspace directory
$ cd ~/cse443
$ # Use ls to check if workspace.code-workspace file is in pwd
$ # Next copy the basic template for a C++ project
$ cp -r /fs/ess/PMIU0184/cse443/templates/basic exercise6
$ # Copy the starter code for this exercise
$ cp /fs/ess/PMIU0184/cse443/exercises/exercise6/* exercise6
```

4. Now add the newly created exercise4 directory to VS-Code Briefly study the starter code in `main.cpp`. It is a very simple program that generates a lot random numbers, sorts them and prints the middle value.

5. Now from the terminal (not via NetBeans) compile the program as shown below. **Note**: the whole command is on 1-line but appears wrapped due to the line being long. The flags "`–fopenmp -D_GLIBCXX_PARALLEL`" flags enable automatic multithreading of the `std::sort()` algorithm.

```
$ g++ -g -Wall -std=c++17 -O3 -fopenmp -D_GLIBCXX_PARALLEL
main.cpp -o main
```

6. Next create an interactive job on the cluster to reserve 8-cores on 1-compute node:

```
$ sinteractive -A PMIU0184 -N 1 -n 8
```

7. Once the job has started run the program using `/usr/bin/time` command using different numbers of threads (by changing `OMP_NUM_THREADS=`*n*, change the value of *n* to 1, 2, 4, 6, and 8) using the command below and record the runtime statistics in the table below. Run each thread setting 3 times and record the values from the 3rd run.

```
$ OMP_NUM_THREADS=n /usr/bin/time -v ./main
```

Observations:

n	**Time in seconds**			**%CPU**
	User	**System**	**Elapsed**	
1	10.76	0.08	0:10.92	99
2	11.23	0.18	0:06.19	184
4	11.47	0.19	0:03.68	316
6	12.63	0.2	0:02.92	439
8	12.95	0.19	0:02.45	535

Once you have recorded your timings, double check your timings with your neighbor or your instructor.

8. Finally stop your interactive job using the `exit` command.

Part #2: Inferences

Using the above observations draw inferences about the following runtime characteristics of the program:

1. From the lecture, briefly describe what does `user` time indicate?

   total cpu time for running instructions of user s code

2. From the lecture, briefly describe what does `elapsed` time indicate?

   runtime of program (as measured by stopwatch) **the most important for many ppl**

3. From the lecture, briefly describe what does `%cpu` indicate?

   e.g. if %cpu is 190%, on average 1.9 CPUs were used for this job

4. Why does the `elapsed` time of the program decrease as the number of threads are increased?

   Instructions are divided on multiple cores, decreases elapse time, each core has “less” things to do

5. If `elapsed` time is decreasing, then why does `user` time of the program slightly increase as the number of threads are increased?

   We have same number of instructions but we are spreading them among multiple nodes, which still has to do the same job

Part #3: Submit files to Canvas

Upload the following files to Canvas:

1. Upload this MS-Word document (duly filled with the necessary information) saved as PDF using the naming convention **`MUid_ex6.pdf`**.