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

CSE-443/543: High Performance Computing

Exercise #8

Max Points: 20

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

Objective: The objective of this exercise is to gain some familiarity with:

- Working with profilers, specifically `perf`.
- Understanding control hazards and branch prediction in action.

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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Background

Detecting regions with performance issues in program is a challenging task, particularly in large software systems. Profilers are special software programs that instrument, monitor, record, and report performance profile of a given program. The performance profile provides detailed runtime statistics about the program. The profile information is used to identify performance bottlenecks or "hot spots" in programs.

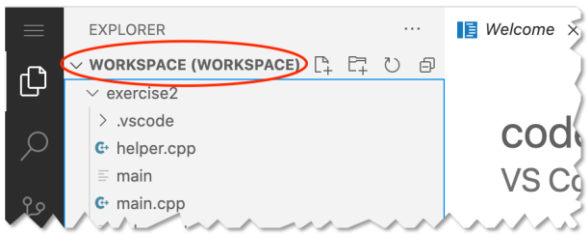
Note: Performance profiles only enable identification of "hot spots". They do not provide information on how to fix the performance bottleneck. Fixing the performance bottleneck will require appropriately reworking the program using different algorithms, data structures, or instructions.

Part #1: Submit job to run with perf profiler

Estimated time: 15 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 exercise8
$ # Copy the starter code for this exercise
$ cp /fs/ess/PMIU0184/cse443/exercises/exercise8/* exercise8
```

4. In this exercise we will reuse the solution for Exercise #7 which compared the performance of `if` vs. `switch` statements.

5. Review the supplied SLURM script for this project. Note how the script compiles and runs the program.

6. Submit your SLURM job as

```
$ sbatch Exercise8_slurm.sh
```

The above job will be queued and then take several seconds to start and run. Once the job ends, you will see an output text file in the format `slurm-<`*JobID*`>.out` (e.g., `slurm-12345.out`) with the results.

> **Note**: While you are waiting for your job to run complete the next part of this exercise.

Part #2: Review profiler background

Estimated time: 10 minutes

1. State one advantage and one disadvantage of hardware profilers?

   + more accurate; - expensive

2. What is the difference between a hardware profiler and a hardware-assisted profiler?

   Hardware profiler : purely specialized hardware for profiling purposes, **Hardware assisted profiler** uses partially hardware partially software for efficient profiling, has to use specialized operating system

3. Briefly describe 3 ways in which software profilers instrument a program/code to gather profile information.

   1. **Manual**: User would defined (by writing some commands) which lines of code has to be profiled
   2. **Compiler assisted**: compiler insert the code in order to make use profiling
   3. **Runtime instrumentation**: binary exe file is being modified directly just before running

Part #3: Record & analyze profiler information

Estimated time: 10 minutes

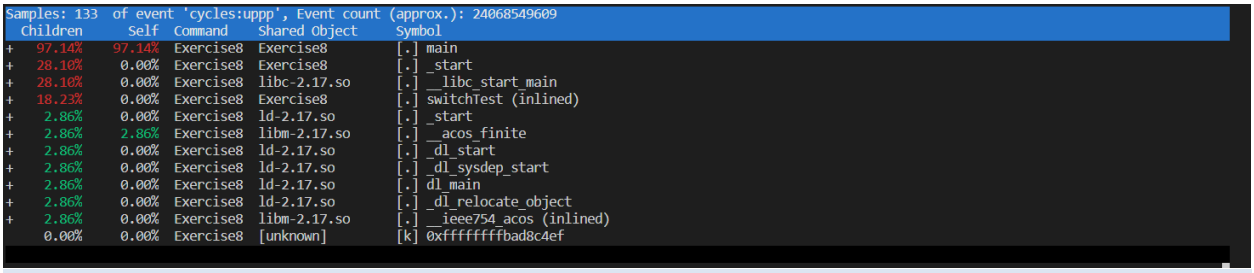
Once your job completes, record the following information from output of the job file. Record the average of the statistics from 3 runs of Linux `perf`:

`perf` statistics (average of 3 runs)	**Using `switch`**	**Using `if`**
`Time elapsed (seconds)`	6.65	6.51
`instructions`	45,049,349,536	82,798,860,843
`CPI (insns per cycle)`	1.87	3.51
`branches`	2,446,278,328	15,446,161,068
`branch-misses` (i.e., cases where CPU prediction was incorrect)	144,5836	128,251

From the above table, note how the instructions executed for the `if`-case is much higher. Then how is it running almost at the same speed (if not slightly faster) then the `switch`-case? Specifically discuss control hazards and branch prediction (using branch-misses data)

In if case it is easier to correctly predict the path than in the switch. Also we can see that even if the instructions are higher, CPI is also higher in **if.** In the case of if, we can see less branches missed , therefore we can assume that **if** program run way smoother than **switch**.

View the recorded perf trace using the command `perf report -i perf_switch.data`. Copy-paste a screenshot of `perf` showing the runtime profile for the program using the `switch` version of the benchmark below



```
Samples: 133  of event 'cycles:uppp', Event count (approx.): 24068549609
  Children      Self  Command    Shared Object      Symbol
+   97.14%    97.14%  Exercise8  Exercise8          [.] main
+   28.10%     0.00%  Exercise8  Exercise8          [.] _start
+   28.10%     0.00%  Exercise8  libc-2.17.so       [.] __libc_start_main
+   18.23%     0.00%  Exercise8  Exercise8          [.] switchTest (inlined)
+    2.86%     0.00%  Exercise8  ld-2.17.so         [.] _start
+    2.86%     2.86%  Exercise8  libm-2.17.so       [.] __acos_finite
+    2.86%     0.00%  Exercise8  ld-2.17.so         [.] _dl_start
+    2.86%     0.00%  Exercise8  ld-2.17.so         [.] _dl_sysdep_start
+    2.86%     0.00%  Exercise8  ld-2.17.so         [.] dl_main
+    2.86%     0.00%  Exercise8  ld-2.17.so         [.] _dl_relocate_object
+    2.86%     0.00%  Exercise8  libm-2.17.so       [.] __ieee754_acos (inlined)
     0.00%     0.00%  Exercise8  [unknown]          [k] 0xffffffffbad8c4ef
```

View the recorded perf trace using the command `perf report -i perf_if.data`. Copy-paste a screenshot of `perf` showing the runtime profile for the program using the `if` version of the benchmark below:

```
Samples: 129  of event 'cycles:uppp', Event count (approx.): 23576654688
  Children      Self  Command    Shared Object      Symbol
+   95.98%    95.98%  Exercise8  Exercise8          [.] main
+   27.11%     0.00%  Exercise8  Exercise8          [.] _start
+   27.11%     0.00%  Exercise8  libc-2.17.so       [.] __libc_start_main
+   21.69%     0.00%  Exercise8  Exercise8          [.] ifTest (inlined)
+   13.18%     0.00%  Exercise8  Exercise8          [.] useIf (inlined)
+    4.02%     0.00%  Exercise8  ld-2.17.so         [.] _start
+    4.01%     4.01%  Exercise8  ld-2.17.so         [.] strcmp
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] _dl_start
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] _dl_sysdep_start
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] dl_main
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] _dl_relocate_object
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] _dl_lookup_symbol_x
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] do_lookup_x
+    4.01%     0.00%  Exercise8  ld-2.17.so         [.] check_match.9525
     0.00%     0.00%  Exercise8  [unknown]          [k] 0xffffffffbad8c4ef
Tip: If you prefer Intel style assembly, try: perf annotate -M intel
```

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.pdf`**.