OpenMP Lab Assignment

Overview

The goal of these exercises is to familiarize you with OpenMP environment and make our first parallel codes with OpenMP. We will also record the code performance and understand race condition and false sharing. This laboratory contains four exercises, each with step-by-step instructions below.

For your experiments, you are going to use a node of the *Beskow* supercomputer. To run your code on Beskow, you need first to generate your executable. It is very important that you include a compiler flag telling the compiler that you are going to use OpenMP. If you forget the flag, the compiler will happily ignore all the OpenMP directives and create an executable that runs in serial. Different compilers have different flags. When using Cray compilers, the OpenMP flag is –openmp.

To compile your C OpenMP code using the default Cray compilers:

```
cc –O2 –openmp –lm name_source.c –o name_exec
```

In Fortran, you need to use the intel compiler. On Beskow, you first need to switch first from Cray to Intel compiler with:

```
module swap PrgEnv-cray PrgEnv-intel
```

and then compile with:

```
ftn –fpp –O2 –openmp –lm name_source.f90 –o name_exec
```

Very Important: Do not copy and paste from this document to your terminal since the – symbol will create problems when compiling.

To run your code on Beskow, you will need to have an interactive allocation:

```
salloc -N 1 -t 4:00:00 -A summer-2017
```

To set the number of threads, you need to set the OpenMP environment variable:

```
export OMP_NUM_THREADS=<number of threads>
```

To run an OpenMP code on a computing node of Beskow:

```
aprun -n 1 -d number of threads -cc none ./name_exec
```

Exercise 1 – OpenMP Hello World, get familiar with OpenMp Environment

Concepts: Parallel regions, parallel, thread ID

Here we are going to implement the first OpenMP program. Expected knowledge includes basic understanding of OpenMP environment, how to compile an OpenMP program, how to set the number of OpenMP threads and retrieve the thread ID number at runtime.

Your code using 4 threads should behave similarly to:

Input:

```
aprun -n 1 -d 4 -cc none ./hello
```

Output:

```
Hello World from Thread 3
Hello World from Thread 0
Hello World from Thread 2
Hello World from Thread 1
```

Instructions: Write a C/Fortran code to make each OpenMP thread print `Hello World from Thread X!` with `X` = thread ID.

Hints:

- Remember to include OpenMP library
- Retrieve the ID of the thread with `omp_get_thread_num()` in C or in Fortran `OMP_GET_THREAD_NUM()`.

Questions:

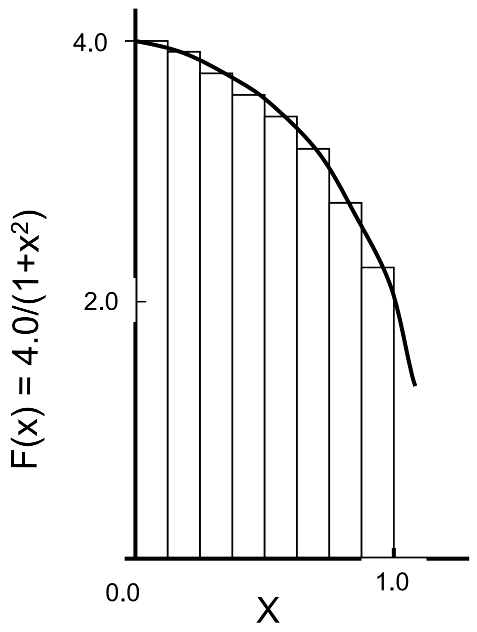
- How do you change the number of threads?
- How many different ways are there to change the number of threads? Which one are those?
- How can you make the output ordered from thread 0 to thread 4?

Exercise 2 - Creating Threads: calculate pi in parallel only using the `parallel` pragma

Concepts: Parallel, default data environment, runtime library calls

Here we are going to implement a first parallel version of the `pi.c` / `pi.f90` code to calculate the value of pi using the parallel construct.

The figure below shows the numerical technique, we are going to use to calculate pi.



Mathematically, we know that:

$$\int_0^1 \frac{4.0}{(1+x^2)}\, dx = \pi$$

We can approximate the integral as a sum of rectangles:

$$\sum_{i=0}^{N} F(x_i)\Delta x \approx \pi$$

Where each rectangle has width Δx and height $F(x_i)$ at the middle of interval i.

Figure 1 We calculate PI solving an integral numerically

A simple serial C code to calculate pi is the following:

```
static long num_steps = 100000000;
double step;

int main(){
        int i;
        double x, pi, sum = 0.0;
        double start_time, run_time;
    step = 1.0/(double) num_steps;
        for (i=1;i<= num_steps; i++){
                x = (i-0.5)*step;
                sum = sum + 4.0/(1.0+x*x);
        }
        pi = step * sum;
}
```

Instructions: Create a parallel version of the `pi.c` / `pi.f90` program using a parallel construct: `#pragma omp parallel`. Run the parallel code and take the execution time with 1, 2,4,8,16, 32 threads. Record the timing.

Pay close attention to shared versus private variables.

- In addition to a `parallel` construct, you might need the runtime library routines:

- `int omp_get_num_threads();` to get the number of threads in a team
- `int omp_get_thread_num();` to get thread ID
- `double omp_get_wtime();` to get the time in seconds since a fixed point in the past
- `omp_set_num_threads();` to request a number of threads in a team

Hints:

- Use a parallel construct: `#pragma omp parallel.`
- Divide loop iterations between threads (use the thread ID and the number of threads).
- Create an accumulator for each thread to hold partial sums that you can later combine to generate the global sum, i.e.,

```
#define MAX_THREADS 4
…
int main ()
{
            double pi, full_sum = 0.0;
            double sum[MAX_THREADS];
     for (j=1;j<=MAX_THREADS ;j++) {
       #pragma omp parallel
       {
        …
               sum[id] = 0.0;
        for (i …){
                       x = (i+0.5)*step;
                       sum[id] = sum[id] + 4.0/(1.0+x*x);
               }
       }
     // calculate full_sum iterating over sum[id]
     …
     pi = step * full_sum;
     …
  }
}
```

Questions:

- How does the execution time change varying the number of threads? Is what you expected? If not, why you think it is so?
- Is there any technique you heard in class to improve the scalability of the technique? How would you implement it?

Exercise 3 - calculate pi using `critical` and `atomic` directives

Concepts: parallel region, synchronization, critical, atomic

Here we are going to implement a second and a third parallel version of the `pi.c` / `pi.f90` code to calculate the value of pi using the `critical` and `atomic` directives.

Instructions: Create two new parallel versions of the `pi.c` / `pi.f90` program using the parallel construct `#pragma omp parallel` and 1) `#pragma omp critical` 2) `#pragma omp atomic`. Run the two new parallel codes and take the execution time with 1, 2,4,8,16, 32 threads. Record the timing in a table.

Hints:

- We can use a shared variable pi to be updated concurrently by different threads. However, this variable needs to be protected with a critical section or an atomic access.
- Use critical and atomic before the update pi += step

Questions:

- What would happen if you hadn't used critical or atomic a shared variable?
- How does the execution time change varying the number of threads? Is it what you expected?
- Do the two version of the codes differ in performance? If so, what do you think it is the reason?

Exercise 4 – calculate pi with a loop and a reduction

Concepts: worksharing, parallel loop, schedule, reduction

Here we are going to implement a fourth parallel version of the `pi.c` / `pi.f90` code to calculate the value of pi using `omp for` and reduction operations.

Instructions: Create a new parallel versions of the `pi.c` / `pi.f90` program using the parallel construct `#pragma omp for` and reduction operation. Run the new parallel code and take the execution time for 1, 2,4,8,16, 32 threads. Record the timing in a table. Change the schedule to dynamic and guided and measure the execution time for 1, 2,4,8,16, 32 threads.

Hints:

To change the schedule, you can either change the environment variable with `export OMP_SCHEDULE=type` where type can be any of `static, dynamic, guided` or in the source code as `omp parallel for schedule(type).`

Questions:

- What is the scheduling that provides the best performance? What is the reason for that?
- What is the fastest parallel implementation of `pi.c` / `pi.f90` program? What is the reason for being the fastest? What would be an even faster implementation of `pi.c` / `pi.f90` program?