T04: OpenMP - Write a parallel code to perform the Vector Dot Product for N Double Precision floating point numbers

CS24M1005 – SINDHIYA R

Write OpenMP Parallel Code for Sum of N - Double Precision Floating Point Numbers. Give input very large at least 1 million - You can dump larger double precision values in a file and read from it and perform addition.

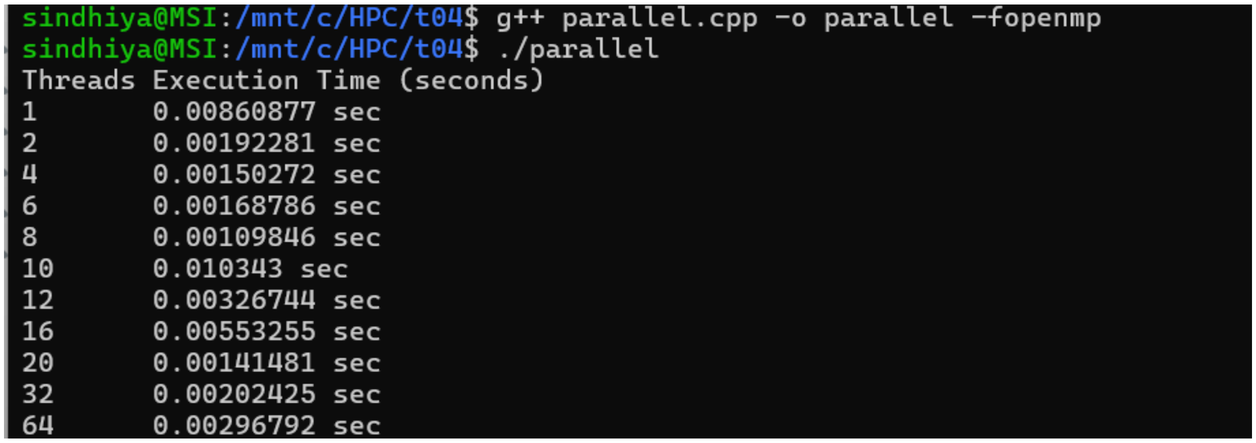
<u>CODE FOR GENERATING INPUT:</u>

```
#include <iostream>
#include <fstream>
#include <cstdlib>

#define N 1000000  // 1 Million

int main() {
    std::ofstream file("input.txt");
    srand(42);  // Seed for reproducibility
    for (int i = 0; i < N; i++) {
        file << (double)(rand() % 1000) / 100.0 << " ";  // Random double values
    }
    file.close();
    std::cout << "File input.txt generated with " << N << " double values.\n";
    return 0;
}
```

1) Parallel Code for multiplication - 5 Marks

```
#include <iostream>
#include <fstream>
#include <vector>
#include <omp.h>

#define N 1000000

int main() {
    std::vector<double> A(N), B(N);
    std::ifstream file("input.txt");

    if (!file) {
        std::cerr << "Error opening file!" << std::endl;
        return 1;
    }

    for (int i = 0; i < N; i++) {
        file >> A[i];
        B[i] = A[i] * 2;
    }
    file.close();

    int threads[] = {1, 2, 4, 6, 8, 10, 12, 16, 20, 32, 64};
    int num_tests = sizeof(threads) / sizeof(threads[0]);

    std::cout << "Threads\tExecution Time (seconds)\n";

    for (int t = 0; t < num_tests; t++) {
        double dot_product = 0.0;
        omp_set_num_threads(threads[t]);

        double start_time = omp_get_wtime();

        #pragma omp parallel for reduction(+:dot_product)
        for (int i = 0; i < N; i++) {
            dot_product += A[i] * B[i];
        }

        double end_time = omp_get_wtime();
        double execution_time = end_time - start_time;

        std::cout << threads[t] << "\t" << execution_time << " sec\n";
    }

    return 0;
}
```

OUTPUT:

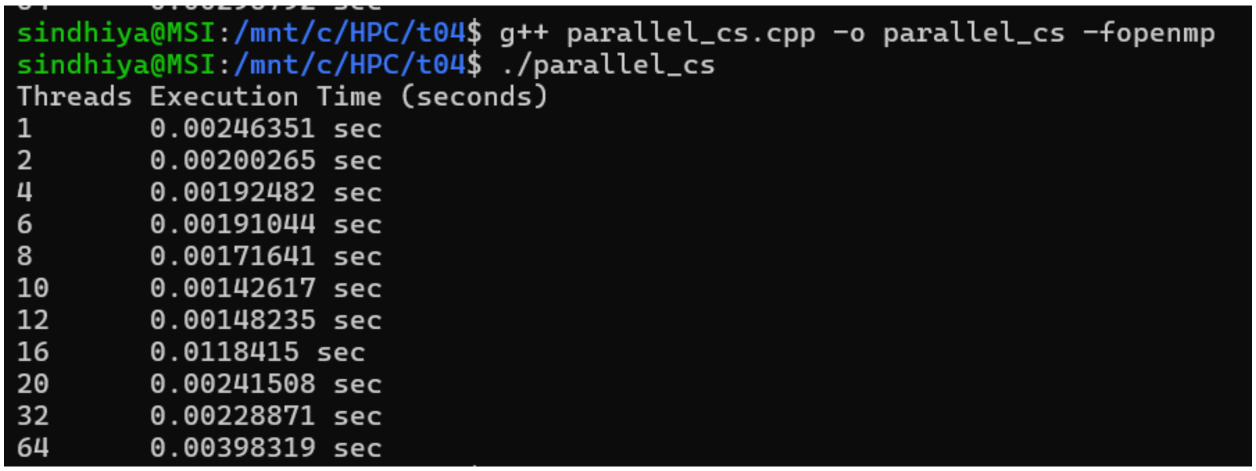


```
sindhiya@MSI:/mnt/c/HPC/t04$ g++ parallel.cpp -o parallel -fopenmp
sindhiya@MSI:/mnt/c/HPC/t04$ ./parallel
Threads Execution Time (seconds)
1       0.00860877 sec
2       0.00192281 sec
4       0.00150272 sec
6       0.00168786 sec
8       0.00109846 sec
10      0.010343 sec
12      0.00326744 sec
16      0.00553255 sec
20      0.00141481 sec
32      0.00202425 sec
64      0.00296792 sec
```

2) Parallel Code Using Critical Section for final addition - 5 Marks

```
#include <iostream>
#include <fstream>
#include <vector>
#include <omp.h>

#define N 1000000

int main() {
    std::vector<double> A(N), B(N);
    std::ifstream file("input.txt");

    if (!file) {
        std::cerr << "Error opening file!" << std::endl;
        return 1;
    }

    for (int i = 0; i < N; i++) {
        file >> A[i];
        B[i] = A[i] * 2;
    }
    file.close();

    int threads[] = {1, 2, 4, 6, 8, 10, 12, 16, 20, 32, 64};
    int num_tests = sizeof(threads) / sizeof(threads[0]);
    std::cout << "Threads\tExecution Time (seconds)\n";

    for (int t = 0; t < num_tests; t++) {
        double dot_product = 0.0;
        omp_set_num_threads(threads[t]);

        double start_time = omp_get_wtime();

        #pragma omp parallel
        {
            double local_sum = 0.0;

            #pragma omp for
            for (int i = 0; i < N; i++) {
                local_sum += A[i] * B[i];
            }

            // Critical section to safely update the global sum
            #pragma omp critical
            {
                dot_product += local_sum;
            }
        }

        double end_time = omp_get_wtime();
        double execution_time = end_time - start_time;

        std::cout << threads[t] << "\t" << execution_time << " sec\n";
    }

    return 0;
}
```

OUTPUT:



```
sindhiya@MSI:/mnt/c/HPC/t04$ g++ parallel_cs.cpp -o parallel_cs -fopenmp
sindhiya@MSI:/mnt/c/HPC/t04$ ./parallel_cs
Threads Execution Time (seconds)
1       0.00246351 sec
2       0.00200265 sec
4       0.00192482 sec
6       0.00191044 sec
8       0.00171641 sec
10      0.00142617 sec
12      0.00148235 sec
16      0.0118415 sec
20      0.00241508 sec
32      0.00228871 sec
64      0.00398319 sec
```

3) Report - Thread vs Time - 5 Marks

Threads	Execution Time (Reduction)	Execution Time (Critical)
1	0.00860877	0.00246351
2	0.00192281	0.00200265
4	0.00150272	0.00192482
6	0.00168786	0.00191044
8	0.00109846	0.00171641
10	0.010343	0.00142617
12	0.00326744	0.00148235
16	0.00553255	0.0118415
20	0.00141481	0.00241508
32	0.00202425	0.00228871
64	0.00296792	0.00398319

Report – Thread vs Time:

1. **Reduction is More Efficient Overall**: The Reduction Method consistently achieves lower execution times compared to the Critical Section Method, indicating that it handles parallelism more efficiently by minimizing synchronization overhead.

2. **Critical Section Becomes a Bottleneck at Higher Threads**: At 16 threads, the Critical Section Method experiences a sharp increase in execution time (11.8415 sec), likely due to excessive contention and thread blocking caused by frequent locking and unlocking.

3. **Reduction Method Shows Performance Degradation Beyond 8 Threads**: While the Reduction Method scales well up to 8 threads (0.00109846 sec), its execution time fluctuates at higher thread counts (e.g., 10 threads = 0.010343 sec, 16 threads = 0.00553255 sec), possibly due to increased overhead from memory access contention.
4. **Critical Section Method is More Stable at Lower Thread Counts**: Up to 10 threads, the Critical Section Method shows relatively stable execution times (~0.0014 - 0.0024 sec). However, as threads increase, synchronization costs outweigh the benefits of parallelism.
5. **Thread Scheduling Overheads Impact**: The Reduction Method benefits significantly from parallelization but is sensitive to excessive threading beyond an optimal number. The Critical Section Method suffers from frequent locking overhead, making it inefficient for higher thread counts.

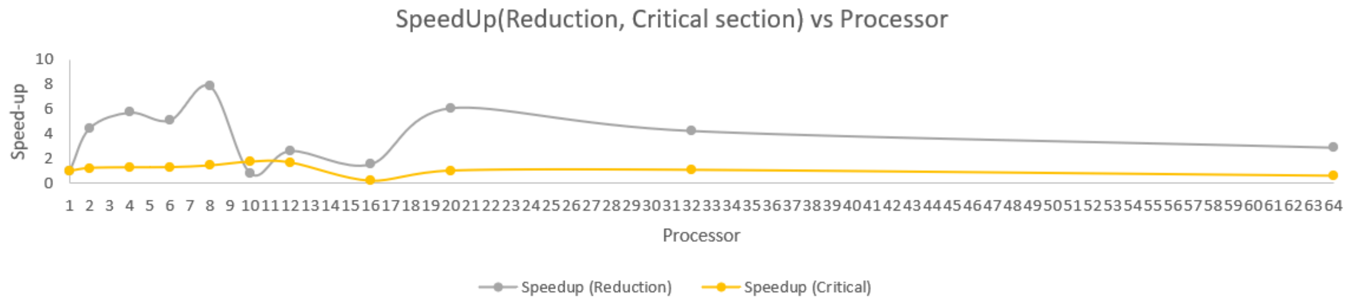
4) Plot Speedup vs Processors - (run the parallel code with 1, 2, 4, 6, 8, 10, 12, 16, 20, 32, 64 Processors) - 10 Marks

Speed Up is calculated by

$$S(P) := T(1)/\dot{T}(P)$$

Where P denoted number of processor and T denotes Time taken by that particular thread.

Threads	Execution Time (Reduction)	Execution Time (Critical)	Speedup (Reduction)	Speedup (Critical)
1	0.00860877	0.00246351	1	1
2	0.00192281	0.00200265	4.48	1.23
4	0.00150272	0.00192482	5.73	1.28
6	0.00168786	0.00191044	5.1	1.29
8	0.00109846	0.00171641	7.84	1.43
10	0.010343	0.00142617	0.83	1.73
12	0.00326744	0.00148235	2.63	1.66
16	0.00553255	0.0118415	1.56	0.21
20	0.00141481	0.00241508	6.09	1.02
32	0.00202425	0.00228871	4.25	1.08
64	0.00296792	0.00398319	2.9	0.61



5) Estimate Parallelization fraction and Inference - 5 Marks

To estimate the parallelization fraction (f) for maximum speedup, we use Amdahl's Law:

$$T(P) = (f/P)*T(1) + (1-f)*T(1)$$

Rearrange to solve for f,

$$f = (1 - T(P)/T(1))/(1 - (1/P))$$

Method	Threads (N)	Highest Speedup	Parallelization Fraction (P)
Reduction	8	7.84	**0.997 (99.7%)**
Critical Section	10	1.73	**0.469 (46.9%)**

Inference:

1. **Reduction method shows significant parallel performance**
   - The highest speedup (7.84×) is achieved at 8 threads, indicating that the reduction method scales well with increasing threads up to this point.
2. **Critical section method has lower scalability**
   - The highest speedup (1.73×) occurs at 10 threads, which is significantly lower than the reduction method, suggesting that critical section synchronization limits performance gains.
3. **Performance degradation beyond a certain point**

- In the reduction method, execution time decreases until 8 threads, but beyond that, fluctuations appear (e.g., at 10 and 16 threads, speedup drops), likely due to thread management overhead and memory bandwidth limitations.

4. **Critical section causes synchronization bottlenecks**
   - Unlike the reduction method, which efficiently sums in parallel, the critical section enforces exclusive access, reducing effective parallelism and causing performance degradation beyond a few threads.
5. **Reduction method maintains higher parallelization fraction**
   - The parallel fraction (f) for reduction is 99.7%, meaning only 0.3% of execution time is serial. This explains its high efficiency for large-scale parallelization.
6. **Critical section limits speedup due to increased contention**
   - With f=46.9, the critical section method has a significant serial portion (53.1%), which limits performance gains, especially as the number of threads increases.
7. **Optimal performance varies for different methods**
   - The best thread count for reduction is 8 (highest speedup), while for critical section, it is 10 (lowest execution time). This means different parallelization strategies require different optimal thread configurations.
8. **Thread oversubscription leads to inefficiency**
   - Beyond 20 threads, performance deteriorates for both methods, likely due to increased context switching, memory contention, and communication overhead.
9. **Reduction method is more suitable for high-performance computing**
   - Since it achieves nearly linear speedup up to 8 threads and maintains a high parallelization fraction, it is better suited for large-scale scientific and engineering applications.

10.Critical section is useful when order or atomicity is required

- Despite lower scalability, the critical section method ensures safe accumulation of results when precision matters, making it more useful in cases requiring controlled updates to shared variables.

Note:

1.All the calculation are done in **excel** and it is attached for your reference.

2. All the **code files** with output are in **github link** and they are attached for your reference