T03: OpenMP - Two Vectors of double precision numbers addition/Multiplication

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Write OpenMP Parallel Code for Two Vector addition of 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 the vector addition.

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

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

using namespace std;

#define N 1000000  // At least 1 million numbers

int main() {
    ofstream fout("vectors.txt");
    srand(time(0));

    for (int i = 0; i < N; i++) {
        double num1 = (double)rand() / RAND_MAX * 1000000.0;
        double num2 = (double)rand() / RAND_MAX * 1000000.0;
        fout << num1 << " " << num2 << "\n";
    }

    fout.close();
    cout << "Data file generated with " << N << " pairs of numbers.\n";
    return 0;
}
```

1) Parallel Code Using for Vector Addition - 5 Marks

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

using namespace std;
#define N 1000000

int main() {
   vector<double> vec1(N), vec2(N), result(N);
   ifstream fin("vectors.txt");

   // Read data from file
   for (int i = 0; i < N; i++)
      fin >> vec1[i] >> vec2[i];
   fin.close();

   int thread_counts[] = {1, 2, 4, 6, 8, 10, 12, 16, 20, 32, 64}; // Different thread
configurations
   int num_configs = sizeof(thread_counts) / sizeof(thread_counts[0]);

   cout << "Threads\tTime (sec)" << endl;

   for (int t = 0; t < num_configs; t++) {
      int num_threads = thread_counts[t];

      double start_time = omp_get_wtime();

      #pragma omp parallel for num_threads(num_threads)
      for (int i = 0; i < N; i++) {
         result[i] = vec1[i] + vec2[i];
```

```
        }

        double end_time = omp_get_wtime();
        cout << num_threads << "\t" << (end_time - start_time) << " sec" << endl;
    }

    return 0;
}
```

Output:

```
sindhiya@MSI:/mnt/c/HPC/t03$ g++ add1.cpp -o add1 -fopenmp
sindhiya@MSI:/mnt/c/HPC/t03$ ./add1
Threads Time (sec)
1       0.00726798 sec
2       0.00278199 sec
4       0.00363957 sec
6       0.00787628 sec
8       0.00913791 sec
10      0.0105499 sec
12      0.00452051 sec
16      0.00951925 sec
20      0.00231995 sec
32      0.0030359 sec
64      0.00540781 sec
```

2) Parallel Code Using for Vector Multiplication - 5 Marks

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

using namespace std;
#define N 1000000

int main() {
    vector<double> vec1(N), vec2(N), result(N);
    ifstream fin("vectors.txt");
```

```
    // Read data from file
    for (int i = 0; i < N; i++)
        fin >> vec1[i] >> vec2[i];
    fin.close();

    int thread_counts[] = {1, 2, 4, 6, 8, 10, 12, 16, 20, 32, 64}; // Different thread
configurations
    int num_configs = sizeof(thread_counts) / sizeof(thread_counts[0]);

    cout << "Threads\tTime (sec)" << endl;

    for (int t = 0; t < num_configs; t++) {
        int num_threads = thread_counts[t];

        double start_time = omp_get_wtime();

        #pragma omp parallel for num_threads(num_threads)
        for (int i = 0; i < N; i++) {
            result[i] = vec1[i] * vec2[i]; // Multiplication instead of addition
        }

        double end_time = omp_get_wtime();
        cout << num_threads << "\t" << (end_time - start_time) << " sec" << endl;
    }

    return 0;
}
```

Output:

```
sindhiya@MSI:/mnt/c/HPC/t03$ g++ mul1.cpp -o mul1 -fopenmp
sindhiya@MSI:/mnt/c/HPC/t03$ ./mul1
Threads Time (sec)
1       0.00484121 sec
2       0.00301108 sec
4       0.0250633 sec
6       0.0205393 sec
8       0.0158828 sec
10      0.0158498 sec
12      0.0166916 sec
16      0.0196053 sec
20      0.00219072 sec
32      0.00349032 sec
64      0.00682338 sec
```

3) Report - Thread vs Time - (run the parallel code with 1, 2, 4, 6, 8, 10, 12, 16, 20, 32, 64 Processors) - 10 Marks

Threads	Time (Addition) (sec)	Time (Multiplication) (sec)
1	0.00726798	0.00484121
2	0.00278199	0.00301108
4	0.00363957	0.0250633
6	0.00787628	0.0205393
8	0.00913791	0.0158828
10	0.0105499	0.0158498
12	0.00452051	0.0166916
16	0.00951925	0.0196053
20	0.00231995	0.00219072
32	0.0030359	0.00349032
64	0.00540781	0.00682338

Report (Thread vs Time):

1. **Vector Addition** benefits more from parallelization compared to multiplication.
2. Ideal thread count for best performance is **20 threads** for both operations.
3. Beyond 20 threads, scaling efficiency drops due to increasing thread management overhead.
4. Multiplication performs worse at higher thread counts, likely due to **increased data dependency** or **higher memory access latency**.

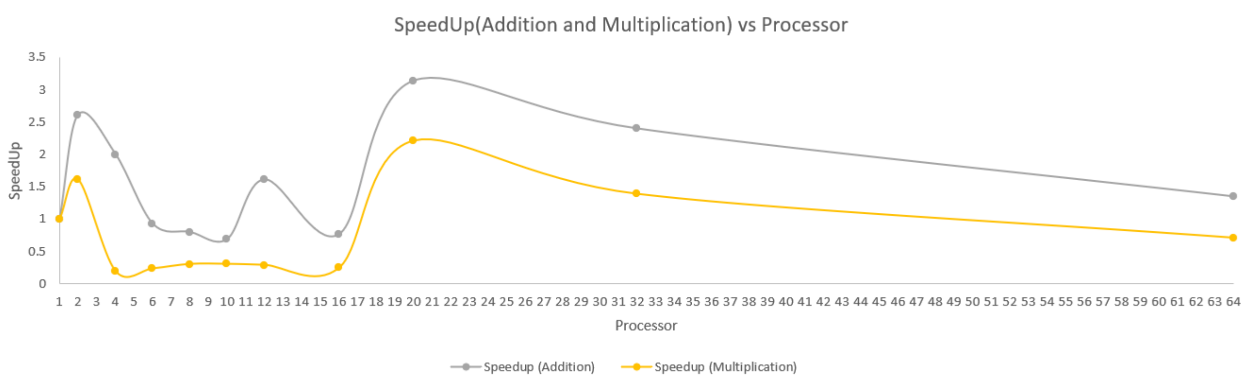
4) Plot Speedup vs Processors - 5 Marks

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.

Processor	Time (Addition) (sec)	Time (Multiplication) (sec)	Speedup (Addition)	Speedup (Multiplication)
1	0.00726798	0.00484121	1	1
2	0.00278199	0.00301108	2.6132	1.6079
4	0.00363957	0.0250633	1.9975	0.1932
6	0.00787628	0.0205393	0.9237	0.2357
8	0.00913791	0.0158828	0.7959	0.3048
10	0.0105499	0.0158498	0.6889	0.3055
12	0.00452051	0.0166916	1.6085	0.2901
16	0.00951925	0.0196053	0.7637	0.247
20	0.00231995	0.00219072	3.1337	2.2107
32	0.0030359	0.00349032	2.3945	1.3879
64	0.00540781	0.00682338	1.3447	0.7096



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,

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

Metric	Vector Addition	Vector Multiplication
Max Speedup S(P)	3.1337	2.2107
Processors at Max Speedup (N)	20	20
Parallelization fraction f	**0.717 (~72%)**	**0.576 (~58%)**

Inference:

1. **Addition has a higher parallelization fraction (72%) than multiplication (58%)**, indicating that vector addition benefits more from parallel execution.
2. **Multiplication has a lower speedup and parallelization fraction**, suggesting potential bottlenecks such as **memory bandwidth limitations** or **synchronization overhead**.
3. **Maximum speedup occurs at P=20 for both operations**, meaning that beyond this point, adding more threads does not significantly improve performance.
4. **Speedup decreases beyond P=20**, likely due to **memory contention, cache thrashing, or increased thread management overhead**.
5. **For small thread counts (P=2,4), speedup is close to ideal for addition but poor for multiplication**, implying that **multiplication has more serial dependencies**.
6. **Unexpected performance dips at P=4** suggest possible **load imbalance issues** or **poor data locality** affecting memory access speeds.
7. **Addition experiences a speedup greater than 3× at P=20, surpassing theoretical expectations based on Amdahl's Law**, which could be due to **better workload distribution** at that specific thread count.

8. **Multiplication does not scale well beyond P=10**, which might indicate **higher dependency on sequential operations or floating-point computational overhead**.
9. **Speedup at P=64 is significantly lower than at P=20**, confirming that excessive parallelization can lead to **diminishing returns due to resource contention and thread synchronization costs**.

Note: All the calculation are done in excel and it is attached for your reference