GPU-Programming
Homework-1
Vector Programming

For this Homework, vector programming is compared with parallel (manual and compiler), and sequential programming.

Code:

```
#include<stdio.h>
#include<stdlib.h>
#include<immintrin.h>
#include<omp.h>
#include<time.h>
int n;
void add_parallel(double *a, double *b, double *c)
{
    int i;
    #pragma parallel for
    for(i=0;i<n;i++)
    {
        c[i]=a[i]+b[i];
    }
}
void add_sequential(double *a, double *b, double *c)
{
    int i;
    for(i=0;i<n;i++)
    {
        c[i]=a[i]+b[i];
    }
}
void add_vector(double *a,double *b,double *c)
{
    int i;
    for(i=0;i<n;i+=4)
    {
        const __m256d t1 = _mm256_load_pd(&a[i]); //avx intrinsic are used with 256 and 512
        const __m256d t2 = _mm256_load_pd(&b[i]);
        const __m256d res = _mm256_add_pd(t1,t2);
        _mm256_stream_pd(&c[i],res);

    }
}
int main(int argc,char **argv)
{
    omp_set_num_threads(20);
    if(argc==2)
    {
        n = atoi(argv[1]);
        double *a = (double *)aligned_alloc(1024,n*sizeof(double));
        double *b = (double *)aligned_alloc(1024,n*sizeof(double));
        double *c = (double *)aligned_alloc(1024,n*sizeof(double));
```

```
                int i;
                clock_t start,stop;
                for(i=0;i<n;i++)
                {
                        a[i] = 1.11;
                        b[i] = 2.22;
                }
                start = clock();
                add_sequential(a,b,c);
                stop = clock();
                printf("Time taken by sequetial add is    :  %lf ms\n",(double)(stop-start)*10e-3);

                start = clock();
                add_vector(a,b,c);
                stop = clock();
                printf("Time taken by vectorised add is   :  %lf ms\n",(double)(stop-start)*10e-3);

                start = clock();
                add_parallel(a,b,c);
                stop = clock();
                printf("Time taken by parallel add is     :  %lf ms\n",(double)(stop-start)*10e-3);
        }
        return 0;
}
```

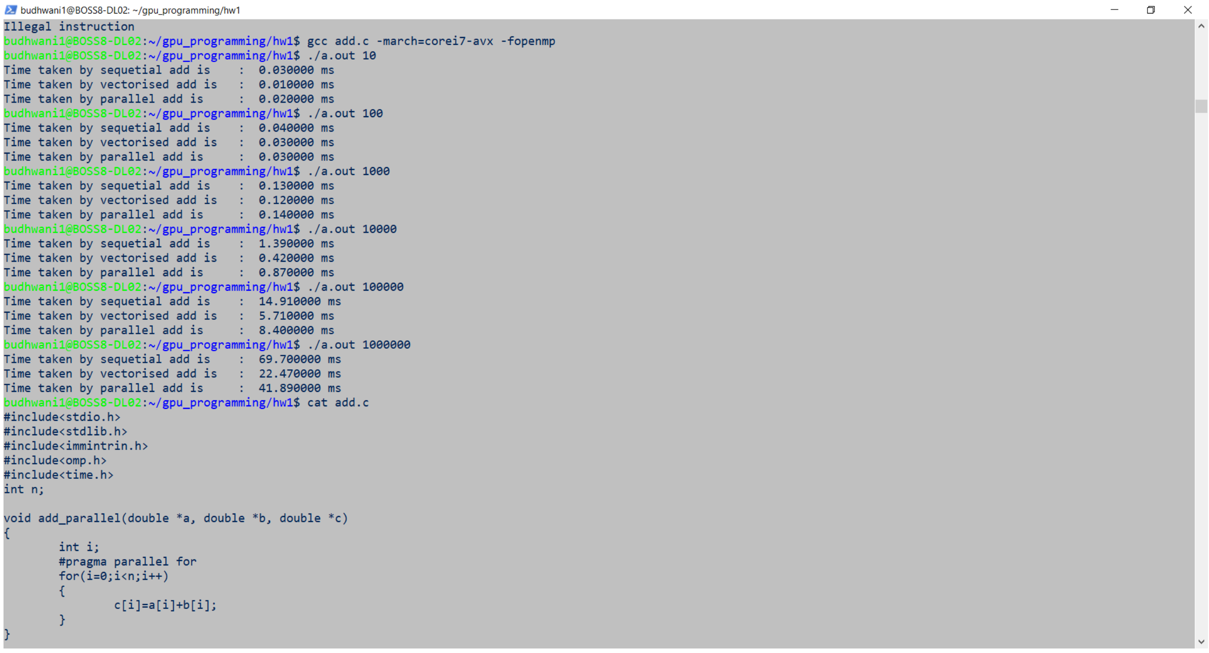
Observations (Tables and Plots):

A. Comparison of vector programming with parallel (manual), and sequential programming.

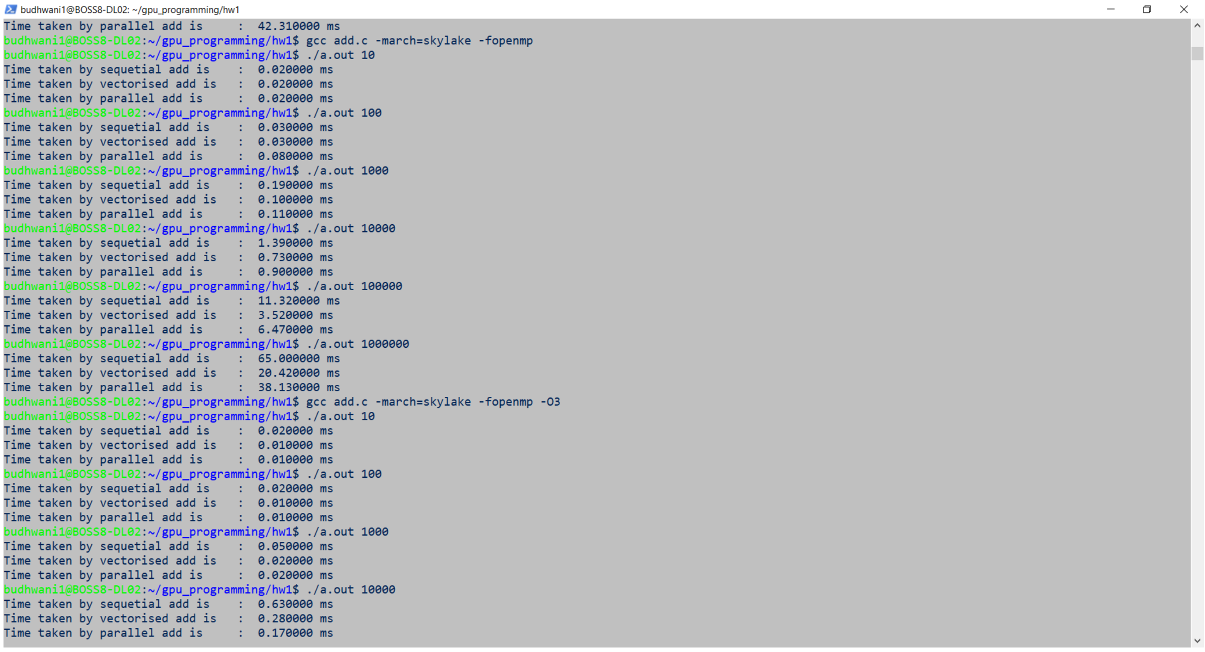
Command used -

gcc add.c -march=corei7-avx -fopenmp

gcc add.c -march=skylake -fopenmp



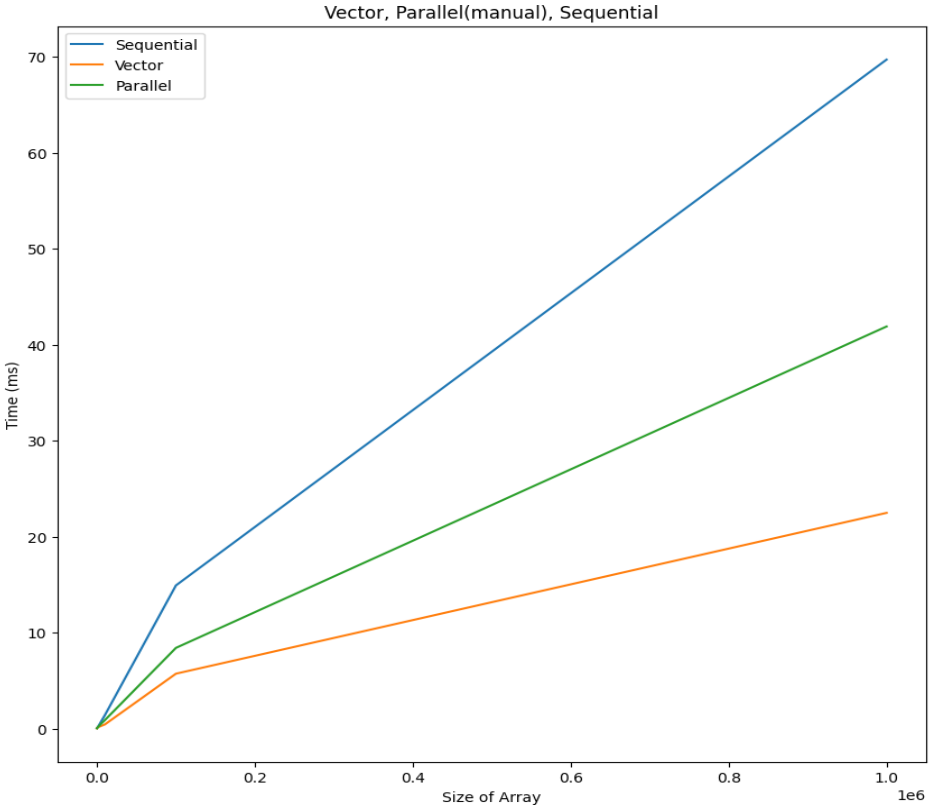
```
Illegal instruction
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ gcc add.c -march=corei7-avx -fopenmp
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10
Time taken by sequetial add is    :  0.030000 ms
Time taken by vectorised add is   :  0.010000 ms
Time taken by parallel add is     :  0.020000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100
Time taken by sequetial add is    :  0.040000 ms
Time taken by vectorised add is   :  0.030000 ms
Time taken by parallel add is     :  0.030000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000
Time taken by sequetial add is    :  0.130000 ms
Time taken by vectorised add is   :  0.120000 ms
Time taken by parallel add is     :  0.140000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10000
Time taken by sequetial add is    :  1.390000 ms
Time taken by vectorised add is   :  0.420000 ms
Time taken by parallel add is     :  0.870000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100000
Time taken by sequetial add is    :  14.910000 ms
Time taken by vectorised add is   :  5.710000 ms
Time taken by parallel add is     :  8.400000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000000
Time taken by sequetial add is    :  69.700000 ms
Time taken by vectorised add is   :  22.470000 ms
Time taken by parallel add is     :  41.890000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ cat add.c
#include<stdio.h>
#include<stdlib.h>
#include<immintrin.h>
#include<omp.h>
#include<time.h>
int n;

void add_parallel(double *a, double *b, double *c)
{
        int i;
        #pragma parallel for
        for(i=0;i<n;i++)
        {
                c[i]=a[i]+b[i];
        }
}
```



budhwani1@BOSS8-DL02: ~/gpu_programming/hw1

```
Time taken by parallel add is      :  42.310000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ gcc add.c -march=skylake -fopenmp
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10
Time taken by sequetial add is     :  0.020000 ms
Time taken by vectorised add is    :  0.020000 ms
Time taken by parallel add is      :  0.020000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100
Time taken by sequetial add is     :  0.030000 ms
Time taken by vectorised add is    :  0.030000 ms
Time taken by parallel add is      :  0.080000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000
Time taken by sequetial add is     :  0.190000 ms
Time taken by vectorised add is    :  0.100000 ms
Time taken by parallel add is      :  0.110000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10000
Time taken by sequetial add is     :  1.390000 ms
Time taken by vectorised add is    :  0.730000 ms
Time taken by parallel add is      :  0.900000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100000
Time taken by sequetial add is     :  11.320000 ms
Time taken by vectorised add is    :  3.520000 ms
Time taken by parallel add is      :  6.470000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000000
Time taken by sequetial add is     :  65.000000 ms
Time taken by vectorised add is    :  20.420000 ms
Time taken by parallel add is      :  38.130000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ gcc add.c -march=skylake -fopenmp -O3
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10
Time taken by sequetial add is     :  0.020000 ms
Time taken by vectorised add is    :  0.010000 ms
Time taken by parallel add is      :  0.010000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100
Time taken by sequetial add is     :  0.020000 ms
Time taken by vectorised add is    :  0.010000 ms
Time taken by parallel add is      :  0.010000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000
Time taken by sequetial add is     :  0.050000 ms
Time taken by vectorised add is    :  0.020000 ms
Time taken by parallel add is      :  0.020000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10000
Time taken by sequetial add is     :  0.630000 ms
Time taken by vectorised add is    :  0.280000 ms
Time taken by parallel add is      :  0.170000 ms
```

S. No.	Size of Array	Time Sequential (ms)	Time Vector (ms)	Time Parallel (ms)
1.	10	0.03	0.01	0.02
2.	100	0.04	0.03	0.03
3.	1000	0.13	0.12	0.14
4.	10000	1.39	0.42	0.87
5.	100000	14.91	5.71	8.40
6.	1000000	69.70	22.47	41.89

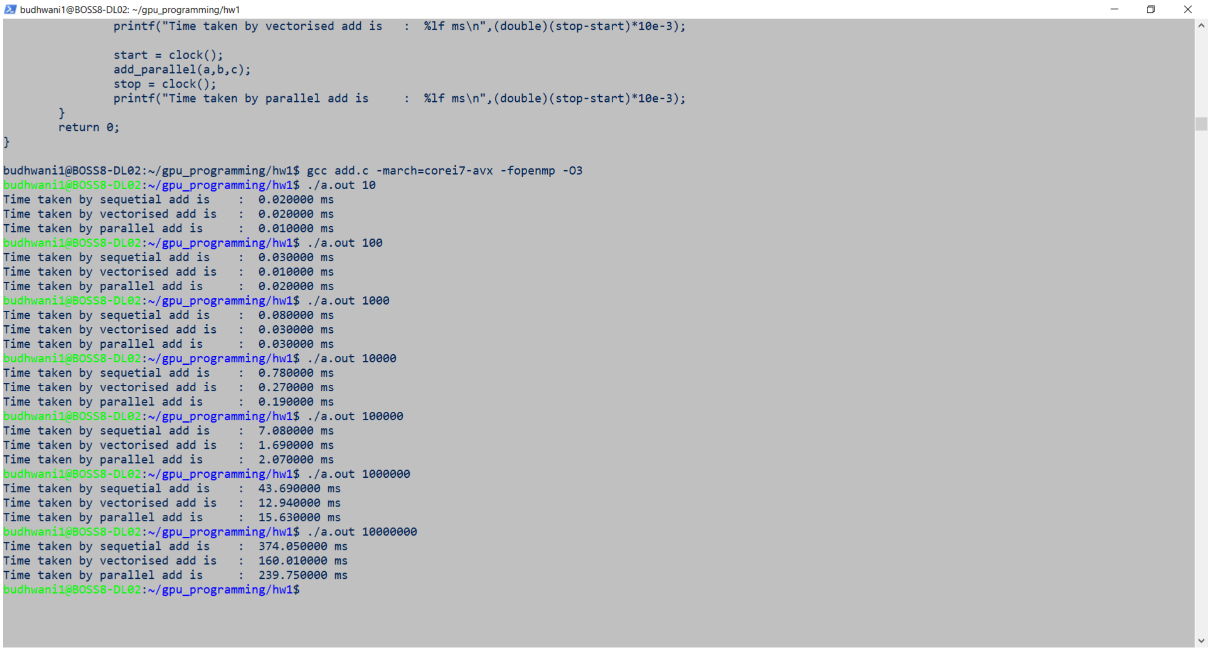

Vector, Parallel(manual), Sequential
Sequential
Vector
Parallel
Time (ms)
0
10
20
30
40
50
60
70
0.0
0.2
0.4
0.6
0.8
1.0
1e6
Size of Array

B. Comparison of vector programming with parallel (compiler), and sequential programming.

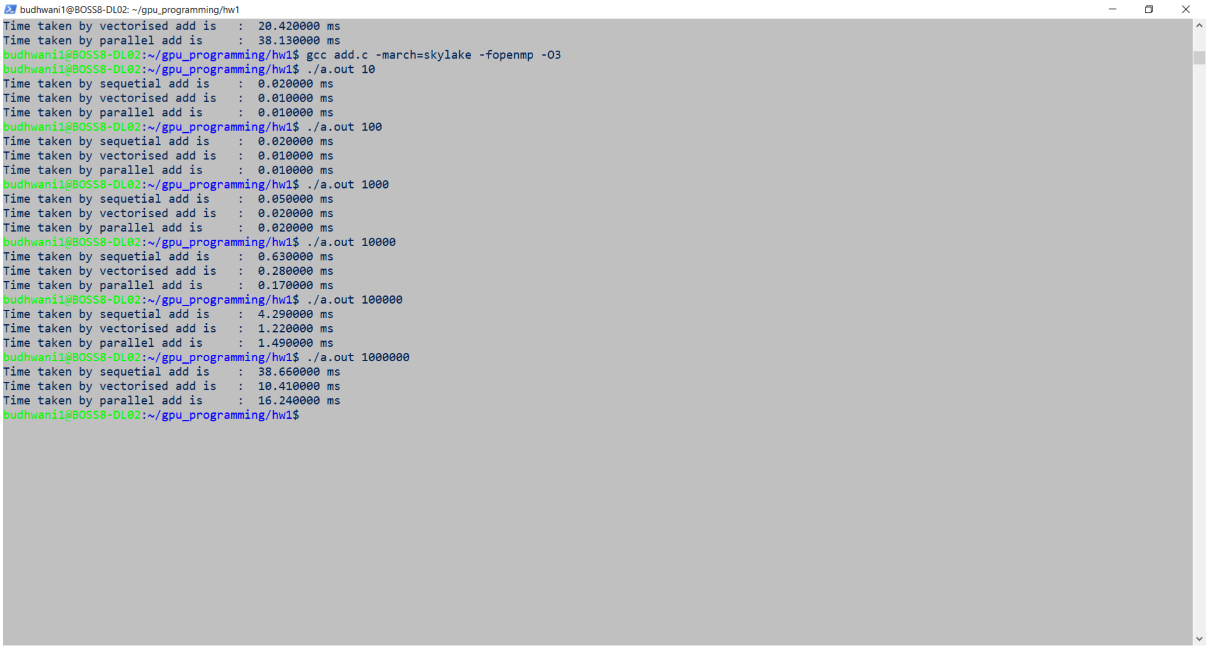
Command used -

gcc add.c -march=corei7-avx -fopenmp -O3 (-O3 flag for compiler-based parallel execution)

gcc add.c -march=skylake -fopenmp -O3 (-O3 flag for compiler-based parallel execution)

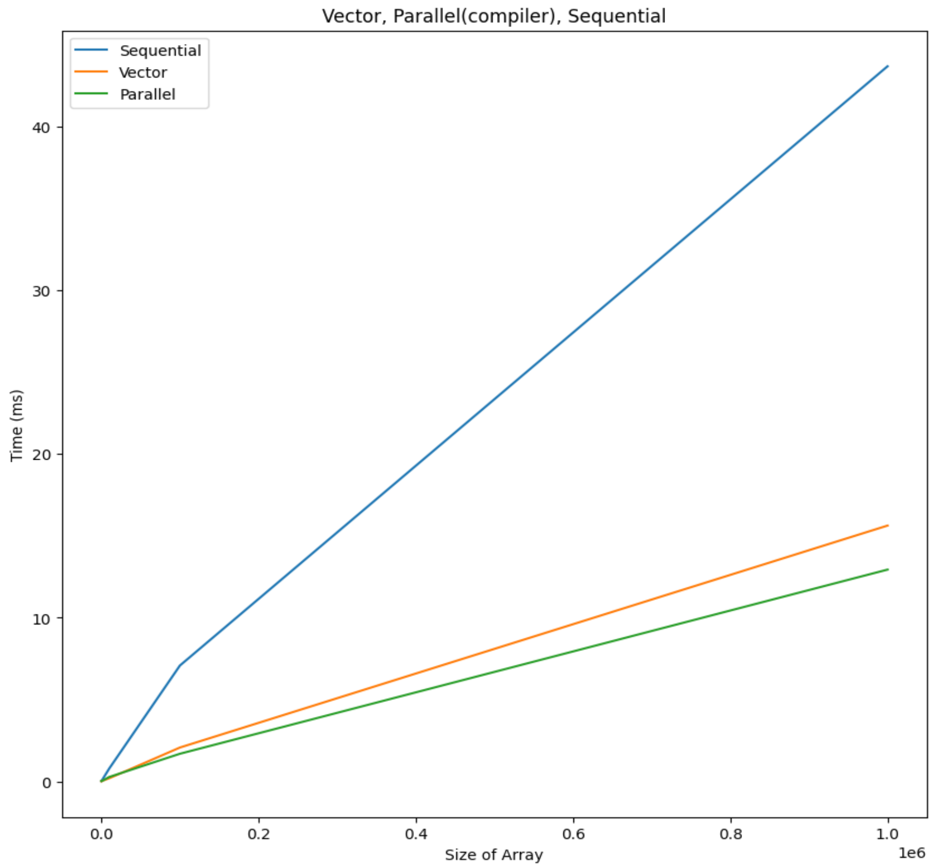


```
                printf("Time taken by vectorised add is   :  %lf ms\n",(double)(stop-start)*10e-3);

                start = clock();
                add_parallel(a,b,c);
                stop = clock();
                printf("Time taken by parallel add is     :  %lf ms\n",(double)(stop-start)*10e-3);
        }
        return 0;
}

budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ gcc add.c -march=corei7-avx -fopenmp -O3
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10
Time taken by sequetial add is    :  0.020000 ms
Time taken by vectorised add is   :  0.020000 ms
Time taken by parallel add is     :  0.010000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100
Time taken by sequetial add is    :  0.030000 ms
Time taken by vectorised add is   :  0.010000 ms
Time taken by parallel add is     :  0.020000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000
Time taken by sequetial add is    :  0.080000 ms
Time taken by vectorised add is   :  0.030000 ms
Time taken by parallel add is     :  0.030000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10000
Time taken by sequetial add is    :  0.780000 ms
Time taken by vectorised add is   :  0.270000 ms
Time taken by parallel add is     :  0.190000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100000
Time taken by sequetial add is    :  7.080000 ms
Time taken by vectorised add is   :  1.690000 ms
Time taken by parallel add is     :  2.070000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000000
Time taken by sequetial add is    :  43.690000 ms
Time taken by vectorised add is   :  12.940000 ms
Time taken by parallel add is     :  15.630000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10000000
Time taken by sequetial add is    :  374.050000 ms
Time taken by vectorised add is   :  160.010000 ms
Time taken by parallel add is     :  239.750000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$
```



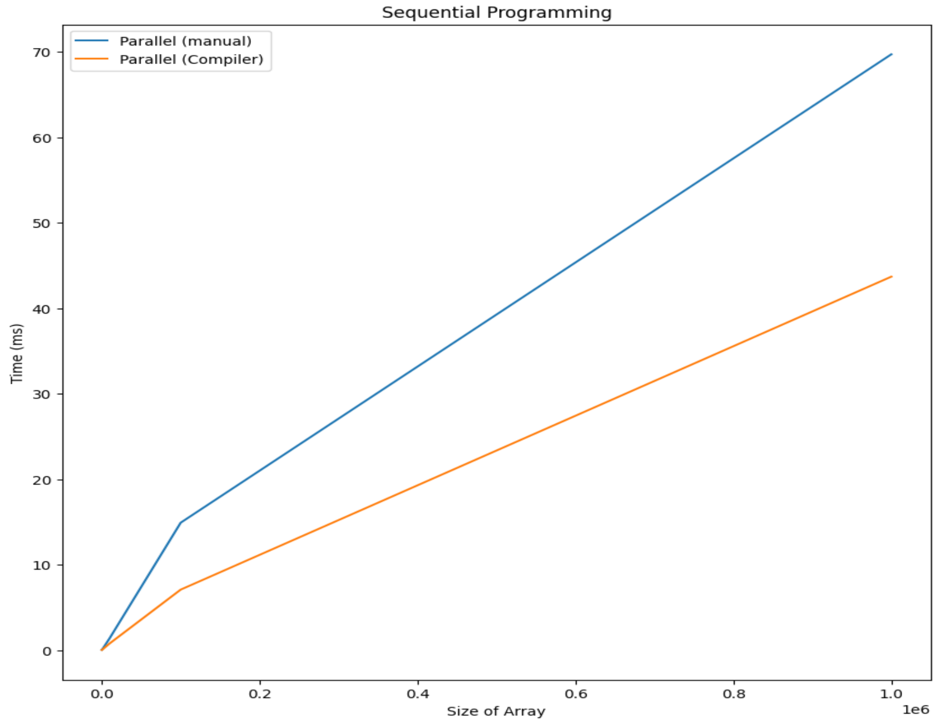
```
Time taken by vectorised add is   :  20.420000 ms
Time taken by parallel add is     :  38.130000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ gcc add.c -march=skylake -fopenmp -O3
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10
Time taken by sequetial add is    :  0.020000 ms
Time taken by vectorised add is   :  0.010000 ms
Time taken by parallel add is     :  0.010000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100
Time taken by sequetial add is    :  0.020000 ms
Time taken by vectorised add is   :  0.010000 ms
Time taken by parallel add is     :  0.010000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000
Time taken by sequetial add is    :  0.050000 ms
Time taken by vectorised add is   :  0.020000 ms
Time taken by parallel add is     :  0.020000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 10000
Time taken by sequetial add is    :  0.630000 ms
Time taken by vectorised add is   :  0.280000 ms
Time taken by parallel add is     :  0.170000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 100000
Time taken by sequetial add is    :  4.290000 ms
Time taken by vectorised add is   :  1.220000 ms
Time taken by parallel add is     :  1.490000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$ ./a.out 1000000
Time taken by sequetial add is    :  38.660000 ms
Time taken by vectorised add is   :  10.410000 ms
Time taken by parallel add is     :  16.240000 ms
budhwani1@BOSS8-DL02:~/gpu_programming/hw1$
```

S. No.	Size of Array	Time Sequential (ms)	Time Parallel (ms)	Time vector (ms)
1.	10	0.02	0.02	0.01
2.	100	0.03	0.01	0.02
3.	1000	0.08	0.03	0.03
4.	10000	0.78	0.27	0.19
5.	100000	7.08	1.69	2.07
6.	1000000	43.69	12.94	15.63

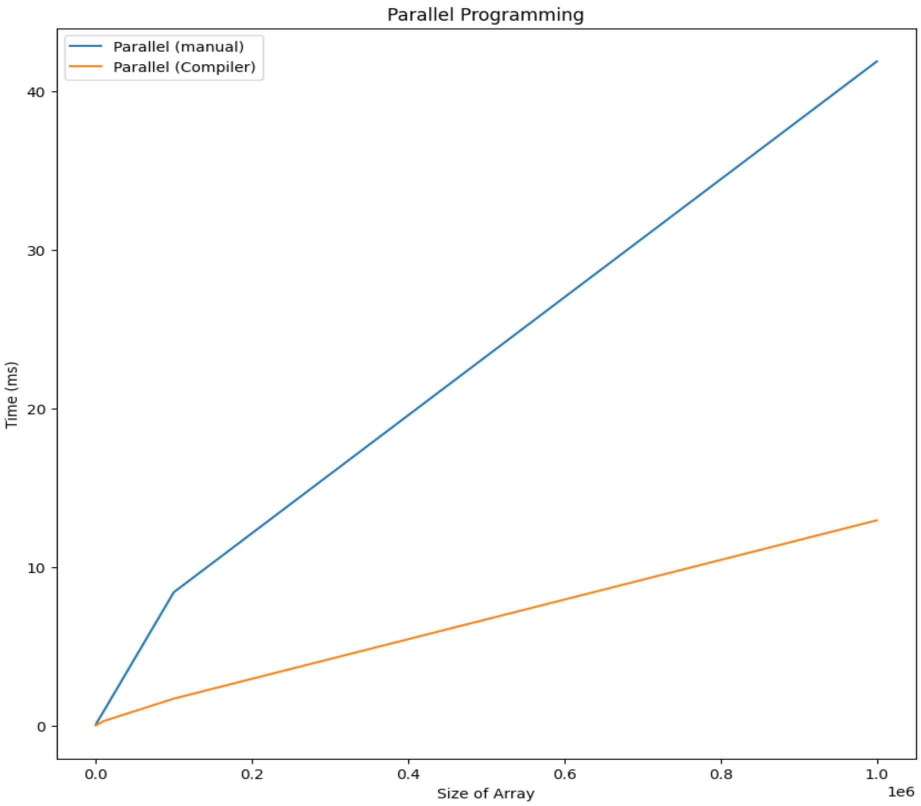


Analysis:

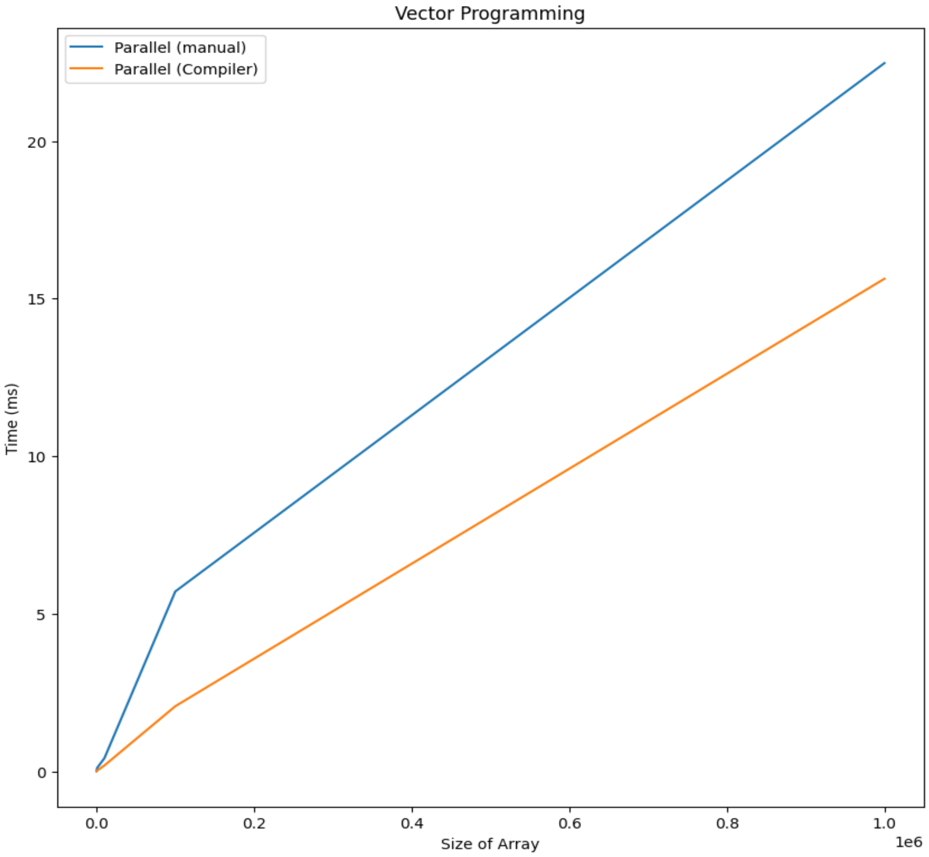
1. Plot of Sequential Programming with Manual and compiler-based parallelism.



2. Plot of Parallel Programming with Manual and compiler-based parallelism.



3. Plot of Vector Programming with Manual and compiler-based parallelism.



4. From the observation it is observed that when manual parallelism is used vector programming takes less time, but when compiler-based parallelism is used parallel programming takes less time after a specific size of array-like 10000.

5. When comparing manual with compiler-based parallelism sequential, parallel, and vector-based programming takes less time in the case of compiler-based, this proves that compiler-based parallel programming is more efficient.

6. Since the number of threads is set to 20 that means all the cores are used and thus there is an overhead involved because of which parallel programming in the case of manual takes more time.

7. Since AVX intrinsics are for bits 128 and 256 bits, 256 bits intrinsics are used while analysis with corei7-avx and skylake [1] as a flag since the latency of skylake is 7 and throughput is 0.5.

Reference:

[1] https://www.intel.com/content/www/us/en/docs/intrinsics-guide/index.html#techs=AVX cited on 18th August 2022.