

# CSE452 Parallel Computing -Midterm Project

## Multi-Threaded Calculation of Pi by Taylor Series

In this project, PI number is calculated by Taylor Series ( $\text{Pi}/4 = +1/1 - 1/3 + 1/5 - 1/7 + 1/9 - \dots$ ) with implementation of multi-threaded programming. C++ language has been used. Divide and conquer method is applied. It means same amount of operations are divided into threads and each thread has done equal work. For inputs cannot be equally divided to threads, remaining part is calculated on main thread. The smallest piece of process that can be calculated in a separate thread is either one addition or one subtraction operation.

Program has got mainly 2 functionalities. User either enters his own inputs (thread number and operation amount) or executes auto demo functionality as it is part of project.

Beside requested tests, I have made some additional tests as well. Tests can be considered as 2 types. Approximation tests and Performance tests.

Approximation tests show how many digits of calculated result is the same as digits of PI.

Performance tests show comparison of calculation durations of different number of threads.

**Performance Tests:** Executions are made on Intel 7700HQ 8 Core CPU.

1<sup>st</sup> example is below:

```
C:\Users\admin\source\repos\parallel\x64\Release\parallel.exe
Going to calculate PI number with an approximation:
By using Tylor Series Method ( $\text{Pi}/4 = 1/1 - 1/3 + 1/5 - 1/7 + 1/9 \dots$ )
With implementation of multi-threaded programming.

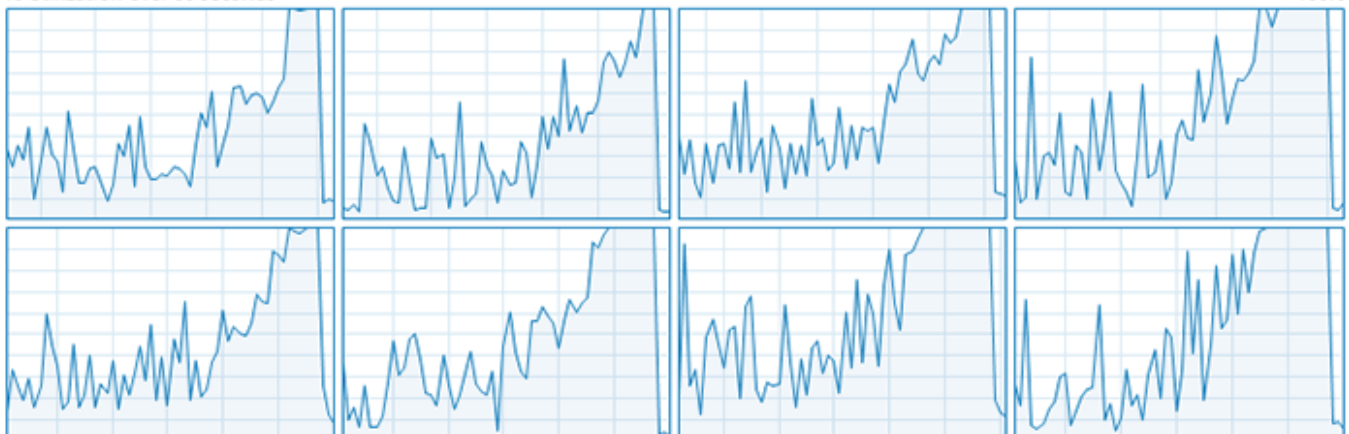
Type "1" for using program with your own inputs.
Type "2" for executing auto test: Running 1 to 8 threads for 10 billion operations.
2
----- PI: 3.14159265358979
Duration of the computation: 41.5778575 seconds for 1 threads. Result: 3.14159265348835
Duration of the computation: 6.3339063 seconds for 2 threads. Result: 3.1415926534882
Duration of the computation: 4.3589076 seconds for 3 threads. Result: 3.14159265348822
Duration of the computation: 3.6624128 seconds for 4 threads. Result: 3.14159265348827
Duration of the computation: 3.3757461 seconds for 5 threads. Result: 3.14159265348808
Duration of the computation: 3.2089787 seconds for 6 threads. Result: 3.14159265348795
Duration of the computation: 3.0817691 seconds for 7 threads. Result: 3.14159265348805
Duration of the computation: 3.008536 seconds for 8 threads. Result: 3.14159265348821
```

CPU

Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz

% Utilization over 60 seconds

100%



2<sup>nd</sup> example is a requirement of project: 1 million operations – 1 to 64 threads. 5 digits approximation.

```
C:\Users\admin\source\repos\parallel\x64\Release\parallel.exe
----- PI: 3.14159265358979
Duration of the computation: 0.0039845 seconds for 1 threads. Result: 3.14159165358977
Duration of the computation: 0.0031966 seconds for 2 threads. Result: 3.14159165358969
Duration of the computation: 0.0014962 seconds for 3 threads. Result: 3.14159165358979
Duration of the computation: 0.0017647 seconds for 4 threads. Result: 3.14159165358978
Duration of the computation: 0.0014845 seconds for 5 threads. Result: 3.14159165358976
Duration of the computation: 0.001366 seconds for 6 threads. Result: 3.14159165358975
Duration of the computation: 0.001266 seconds for 7 threads. Result: 3.14159165358975
Duration of the computation: 0.0014366 seconds for 8 threads. Result: 3.14159165358973
Duration of the computation: 0.0004289 seconds for 9 threads. Result: 3.14159165358973
Duration of the computation: 0.0004571 seconds for 10 threads. Result: 3.14159165358972
Duration of the computation: 0.0004895 seconds for 11 threads. Result: 3.14159165358973
Duration of the computation: 0.000493 seconds for 12 threads. Result: 3.14159165358974
Duration of the computation: 0.0004725 seconds for 13 threads. Result: 3.14159165358974
Duration of the computation: 0.0004632 seconds for 14 threads. Result: 3.14159165358977
Duration of the computation: 0.0004255 seconds for 15 threads. Result: 3.14159165358976
Duration of the computation: 0.0004522 seconds for 16 threads. Result: 3.14159165358976
Duration of the computation: 0.0004391 seconds for 17 threads. Result: 3.14159165358977
Duration of the computation: 0.0005205 seconds for 18 threads. Result: 3.14159165358978
Duration of the computation: 0.0004885 seconds for 19 threads. Result: 3.14159165358978
Duration of the computation: 0.0003752 seconds for 20 threads. Result: 3.14159165358978
Duration of the computation: 0.0003872 seconds for 21 threads. Result: 3.14159165358979
Duration of the computation: 0.0004565 seconds for 22 threads. Result: 3.14159165358979
Duration of the computation: 0.0003942 seconds for 23 threads. Result: 3.14159165358979
Duration of the computation: 0.000385 seconds for 24 threads. Result: 3.14159165358979
Duration of the computation: 0.0003967 seconds for 25 threads. Result: 3.14159165358979
Duration of the computation: 0.0004356 seconds for 26 threads. Result: 3.1415916535898
Duration of the computation: 0.0003683 seconds for 27 threads. Result: 3.14159165358979
Duration of the computation: 0.0003771 seconds for 28 threads. Result: 3.14159165358979
Duration of the computation: 0.0004063 seconds for 29 threads. Result: 3.1415916535898
Duration of the computation: 0.0004366 seconds for 30 threads. Result: 3.1415916535898
Duration of the computation: 0.0004464 seconds for 31 threads. Result: 3.1415916535898
Duration of the computation: 0.0004248 seconds for 32 threads. Result: 3.14159165358979
Duration of the computation: 0.0004103 seconds for 33 threads. Result: 3.14159165358979
Duration of the computation: 0.0004197 seconds for 34 threads. Result: 3.14159165358979
Duration of the computation: 0.0004041 seconds for 35 threads. Result: 3.14159165358979
Duration of the computation: 0.0004633 seconds for 36 threads. Result: 3.14159165358979
Duration of the computation: 0.0004862 seconds for 37 threads. Result: 3.14159165358979
Duration of the computation: 0.0004238 seconds for 38 threads. Result: 3.14159165358979
Duration of the computation: 0.0003626 seconds for 39 threads. Result: 3.14159165358979
Duration of the computation: 0.0004302 seconds for 40 threads. Result: 3.14159165358979
Duration of the computation: 0.0003796 seconds for 41 threads. Result: 3.14159165358979
Duration of the computation: 0.0004015 seconds for 42 threads. Result: 3.14159165358979
Duration of the computation: 0.0004523 seconds for 43 threads. Result: 3.14159165358979
Duration of the computation: 0.000439 seconds for 44 threads. Result: 3.14159165358979
Duration of the computation: 0.0004437 seconds for 45 threads. Result: 3.14159165358979
Duration of the computation: 0.0004956 seconds for 46 threads. Result: 3.14159165358979
Duration of the computation: 0.0003969 seconds for 47 threads. Result: 3.14159165358979
Duration of the computation: 0.000443 seconds for 48 threads. Result: 3.14159165358979
Duration of the computation: 0.0003993 seconds for 49 threads. Result: 3.14159165358979
Duration of the computation: 0.0004343 seconds for 50 threads. Result: 3.14159165358979
Duration of the computation: 0.0004263 seconds for 51 threads. Result: 3.14159165358979
Duration of the computation: 0.0005088 seconds for 52 threads. Result: 3.1415916535898
Duration of the computation: 0.0005223 seconds for 53 threads. Result: 3.14159165358979
Duration of the computation: 0.0004618 seconds for 54 threads. Result: 3.14159165358979
Duration of the computation: 0.0004873 seconds for 55 threads. Result: 3.14159165358979
Duration of the computation: 0.0004872 seconds for 56 threads. Result: 3.14159165358979
Duration of the computation: 0.0004276 seconds for 57 threads. Result: 3.14159165358979
Duration of the computation: 0.0004126 seconds for 58 threads. Result: 3.14159165358979
Duration of the computation: 0.0004301 seconds for 59 threads. Result: 3.14159165358979
Duration of the computation: 0.0004485 seconds for 60 threads. Result: 3.1415916535898
Duration of the computation: 0.0004324 seconds for 61 threads. Result: 3.14159165358979
Duration of the computation: 0.0004407 seconds for 62 threads. Result: 3.14159165358979
Duration of the computation: 0.0004278 seconds for 63 threads. Result: 3.14159165358979
Duration of the computation: 0.0003985 seconds for 64 threads. Result: 3.14159165358979
```

## Approximation Tests:

100 operations make 1-digit approximation

```
C:\Users\admin\source\repos\parallel\x64\Release\parallel.exe
Going to calculate PI number with an approximation:
By using Tylor Series Method ( $PI/4 = 1/1 - 1/3 + 1/5 - 1/7 + 1/9 \dots$ )
With implementation of multi-threaded programming.

Type "1" for using program with your own inputs.
Type "2" for executing auto test: Running 1 to 64 threads for 1m operations.
1
Enter number of operations: 100
Enter number of threads: 8
Duration of the computation: 0.0027352 seconds for 8 threads. Result: 3.13159290355855

Result: 3.13159290355855
PI: 3.14159265358979

Approximation Error: Result - PI = -0.00999975003123899
Approximation Error: PI - Result = 0.00999975003123899
```

10 billion operations make 9-digit approximation

```
Select C:\Users\admin\source\repos\parallel\x64\Release\parallel.exe
By using Tylor Series Method ( $PI/4 = 1/1 - 1/3 + 1/5 - 1/7 + 1/9 \dots$ )
With implementation of multi-threaded programming.

Type "1" for using program with your own inputs.
Type "2" for executing auto test: Running 1 to 64 threads for 1m operations.
1
Enter number of operations: 10000000000
Enter number of threads: 8
Duration of the computation: 3.0195 seconds for 8 threads.

Result: 3.14159265348821
PI: 3.14159265358979

Approximation Error: Result - PI = -1.01587627199251e-10
Approximation Error: PI - Result = 1.01587627199251e-10
```

1 trillion operations make 11-digit approximation

```
Going to calculate PI number with an approximation:
By using Tylor Series Method ( $PI/4 = 1/1 - 1/3 + 1/5 - 1/7 + 1/9 \dots$ )
With implementation of multi-threaded programming.

Enter number of operations: 1000000000000
Enter number of threads: 8

Duration of the computation: 308.787 seconds

Result: 3.14159265358755
PI: 3.14159265358979

Approximation Error: Result - PI = -2.24043006369357e-12
Approximation Error: PI - Result = 2.24043006369357e-12
```