```
////////////////////////////////////////////////////////////////////////////
//                                                                        //
//            FEDERAL UNIVERSITY OF RIO GRANDE DO NORTE - UFRN            //
//                   DIGITAL METROPOLIS INSTITUTE - IMD                   //
//               BACHELOR OF INFORMATION TECHNOLOGY - BTI                 //
//           SPECIAL TOPICS ON INTERNET OF THINGS "B" - IMD0291            //
//                                                                        //
////////////////////////////////////////////////////////////////////////////
//                                                                        //
// Names: pi.h                                                            //
//        report.h                                                        //
//        report.pdf                                                      //
//        calculates-the-pi-value-serial.cpp                              //
//        calculates-the-pi-value-parallel.cpp                            //
//        calculates-serie-parallel-analysis.cpp                          //
//        shellscript_start.sh                                            //
//        README.txt                                                      //
// Date: 14/10/2020                                                       //
// Version: 1.0                                                           //
//                                                                        //
// Author: P.R.O.Lima                                                     //
//                                                                        //
// Repository: https://github.com/r4m0nl1m4/calculates-the-PI-value       //
//                                                                        //
// Software: GNU Compiler Collection (gcc) 9.3.0                          //
//                                                                        //
////////////////////////////////////////////////////////////////////////////
//                                                                        //
// Description: Calculates the PI value by Leibniz formula, developed  for //
// use  on  serie  and  parallel  processors  with local interconnections. //
//                                                                        //
////////////////////////////////////////////////////////////////////////////
//                                                                        //
// To execute:                                                            //
//     ~$ bash shellscript_start.sh                                       //
//                                                                        //
////////////////////////////////////////////////////////////////////////////
```

```
/*
 * CPU Report
 */

model name      : Intel(R) Core(TM) i7-4770K CPU @ 3.50GHz
vendor_id       : GenuineIntel
cpu cores       : 4
siblings        : 8
cache size      : 8192 KB
```

```
/*
 * Problem Size Report
 */

:2000:2000:2000:2000:2000
:4000:4000:4000:4000:4000
:2000:2000:2000:2000:2000
:4000:4000:4000:4000:4000
:2000:2000:2000:2000:2000
:4000:4000:4000:4000:4000
:2000:2000:2000:2000:2000
:4000:4000:4000:4000:4000
```

```
/*
 * PI by Integration using Serie Process Runtime Report In Seconds
 */

:1.60e-05:1.90e-05:2.50e-05:2.30e-05:2.90e-05
:3.70e-05:2.40e-05:6.00e-05:4.60e-05:7.80e-05
:2.30e-05:1.40e-05:1.30e-05:2.70e-05:1.70e-05
:2.30e-05:1.50e-05:5.00e-05:4.30e-05:2.60e-05
:2.00e-05:2.50e-05:2.20e-05:3.50e-05:1.80e-05
:3.10e-05:6.00e-05:1.70e-05:2.30e-05:2.60e-05
:1.70e-05:2.10e-05:1.90e-05:2.40e-05:8.00e-06
:4.00e-05:6.00e-05:5.00e-05:1.90e-05:3.80e-05
```

```
/*
 * CPU Cores Report
 */

:2:2:2:2:2
:2:2:2:2:2
:4:4:4:4:4
:4:4:4:4:4
:6:6:6:6:6
:6:6:6:6:6
:8:8:8:8:8
:8:8:8:8:8
```

```
/*
 * PI by Integration using Parallel Process (MPI) Runtime Report In Seconds
 */

:1.98e-05:1.32e-05:1.57e-05:1.15e-05:2.13e-05
:1.55e-05:2.10e-05:2.53e-05:2.29e-05:1.60e-05
:2.50e-05:2.20e-05:1.95e-05:1.81e-05:1.59e-05
:1.71e-05:2.20e-05:2.52e-05:3.07e-05:2.69e-05
:2.42e-05:2.47e-05:5.73e-05:3.38e-05:5.15e-05
:5.25e-05:5.93e-05:5.04e-05:5.37e-05:5.07e-05
:1.30e-05:9.51e-06:4.50e-05:4.95e-05:6.11e-05
:6.37e-05:6.51e-05:5.77e-05:5.92e-05:5.81e-05
```

```
/*
 * PI by Integration using Parallel Process (MPI) Speedup Report
 */

:0.81:1.44:1.59:2.00:1.36
:2.39:1.14:2.37:2.01:4.88
:0.92:0.64:0.67:1.49:1.07
:1.35:0.68:1.98:1.40:0.97
:0.83:1.01:0.38:1.04:0.35
:0.59:1.01:0.34:0.43:0.51
:1.31:2.21:0.42:0.48:0.13
:0.63:0.92:0.87:0.32:0.65
```

```
/*
 * PI by Integration using Parallel Process (MPI) Efficiency Report
 */

:0.41:0.72:0.80:1.00:0.68
:1.20:0.57:1.19:1.00:2.44
:0.23:0.16:0.17:0.37:0.27
:0.34:0.17:0.49:0.35:0.24
:0.14:0.17:0.06:0.17:0.06
:0.10:0.17:0.06:0.07:0.09
:0.16:0.28:0.05:0.06:0.02
:0.08:0.12:0.11:0.04:0.08
```

```
/*
 * PI by Integration using Parallel Process (MPI) Calculation Report
 */

 2 Cores CPU - Size Problem 2000

  Try 1

    Runtime 1.98e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         1000         2000     0.463648     0.463648
          1            2         1000         2000     1.287002     3.141593
--------------------------------------------------------------------------------
  Try 2

    Runtime 1.32e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         1000         2000     0.463648     0.463648
          1            2         1000         2000     1.287002     3.141593
--------------------------------------------------------------------------------
  Try 3

    Runtime 1.57e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         1000         2000     0.463648     0.463648
          1            2         1000         2000     1.287002     3.141593
--------------------------------------------------------------------------------
  Try 4

    Runtime 1.15e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         1000         2000     0.463648     0.463648
          1            2         1000         2000     1.287002     3.141593
--------------------------------------------------------------------------------
  Try 5

    Runtime 2.13e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         1000         2000     0.463648     0.463648
          1            2         1000         2000     1.287002     3.141593
--------------------------------------------------------------------------------

 2 Cores CPU - Size Problem 4000

  Try 1

    Runtime 1.55e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         2000         4000     0.463648     0.463648
          1            2         2000         4000     1.287002     3.141593
--------------------------------------------------------------------------------
  Try 2

    Runtime 2.10e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         2000         4000     0.463648     0.463648
          1            2         2000         4000     1.287002     3.141593
--------------------------------------------------------------------------------
  Try 3

    Runtime 2.53e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            2         2000         4000     0.463648     0.463648
          1            2         2000         4000     1.287002     3.141593
```

Try 4

Runtime 2.29e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	2	2000	4000	0.463648	0.463648
1	2	2000	4000	1.287002	3.141593

Try 5

Runtime 1.60e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	2	2000	4000	0.463648	0.463648
1	2	2000	4000	1.287002	3.141593

---

4 Cores CPU - Size Problem 2000

Try 1

Runtime 2.50e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	500	2000	0.244979	0.244979
1	4	500	2000	0.874676	1.854590
2	4	500	2000	0.719414	2.574004
3	4	500	2000	0.567588	3.141593

Try 2

Runtime 2.20e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	500	2000	0.244979	0.244979
1	4	500	2000	0.874676	1.854590
2	4	500	2000	0.719414	2.574004
3	4	500	2000	0.567588	3.141593

Try 3

Runtime 1.95e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	500	2000	0.244979	0.244979
1	4	500	2000	0.874676	1.854590
2	4	500	2000	0.719414	2.574004
3	4	500	2000	0.567588	3.141593

Try 4

Runtime 1.81e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	500	2000	0.244979	0.244979
1	4	500	2000	0.874676	1.854590
2	4	500	2000	0.719414	2.574004
3	4	500	2000	0.567588	3.141593

Try 5

Runtime 1.59e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	500	2000	0.244979	0.244979
1	4	500	2000	0.719414	1.699329
2	4	500	2000	0.874676	2.574004
3	4	500	2000	0.567588	3.141593

---

4 Cores CPU - Size Problem 4000

Try 1

Runtime 1.71e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	1000	4000	0.244979	0.244979
1	4	1000	4000	0.874676	1.854590
2	4	1000	4000	0.719414	2.574004
3	4	1000	4000	0.567588	3.141593

Try 2

Runtime 2.20e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	1000	4000	0.244979	0.244979
1	4	1000	4000	0.719414	1.699329
2	4	1000	4000	0.874676	2.574004
3	4	1000	4000	0.567588	3.141593

Try 3

Runtime 2.52e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	1000	4000	0.244979	0.244979
1	4	1000	4000	0.874676	1.854590
2	4	1000	4000	0.719414	2.574004
3	4	1000	4000	0.567588	3.141593

Try 4

Runtime 3.07e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	1000	4000	0.244979	0.244979
1	4	1000	4000	0.719414	1.699329
2	4	1000	4000	0.874676	2.574004
3	4	1000	4000	0.567588	3.141593

Try 5

Runtime 2.69e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	4	1000	4000	0.244979	0.244979
1	4	1000	4000	0.567588	1.547503
2	4	1000	4000	0.874676	2.422179
3	4	1000	4000	0.719414	3.141593

---

6 Cores CPU - Size Problem 2000

Try 1

Runtime 2.42e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	6	333	2000	0.165473	0.165473
1	6	333	2000	0.427729	1.089621
2	6	333	2000	0.568655	1.658276
3	6	333	2000	0.363306	2.021582
4	6	333	2000	0.498343	2.519925
5	6	333	2000	0.627607	3.147533

Try 2

Runtime 2.47e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	6	333	2000	0.165473	0.165473
1	6	333	2000	0.568655	1.230547
2	6	333	2000	0.627607	1.858154

```
         3            6          333         2000     0.498343     2.356497
         4            6          333         2000     0.427729     2.784226
         5            6          333         2000     0.363306     3.147533
--------------------------------------------------------------------------------
  Try 3

    Runtime 5.73e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            6          333         2000     0.165473     0.165473
          1            6          333         2000     0.627607     1.289499
          2            6          333         2000     0.568655     1.858154
          3            6          333         2000     0.498343     2.356497
          4            6          333         2000     0.427729     2.784226
          5            6          333         2000     0.363306     3.147533
--------------------------------------------------------------------------------
  Try 4

    Runtime 3.38e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            6          333         2000     0.165473     0.165473
          1            6          333         2000     0.627607     1.289499
          2            6          333         2000     0.498343     1.787842
          3            6          333         2000     0.427729     2.215572
          4            6          333         2000     0.363306     2.578878
          5            6          333         2000     0.568655     3.147533
--------------------------------------------------------------------------------
  Try 5

    Runtime 5.15e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            6          333         2000     0.165473     0.165473
          1            6          333         2000     0.627607     1.289499
          2            6          333         2000     0.568655     1.858154
          3            6          333         2000     0.498343     2.356497
          4            6          333         2000     0.427729     2.784226
          5            6          333         2000     0.363306     3.147533
--------------------------------------------------------------------------------

 6 Cores CPU - Size Problem 4000

  Try 1

    Runtime 5.25e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            6          666         4000     0.165230     0.165230
          1            6          666         4000     0.626708     1.287627
          2            6          666         4000     0.567855     1.855481
          3            6          666         4000     0.497651     2.353132
          4            6          666         4000     0.427139     2.780272
          5            6          666         4000     0.362806     3.143078
--------------------------------------------------------------------------------
  Try 2

    Runtime 5.93e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            6          666         4000     0.165230     0.165230
          1            6          666         4000     0.362806     1.023725
          2            6          666         4000     0.626708     1.650433
          3            6          666         4000     0.567855     2.218288
          4            6          666         4000     0.497651     2.715938
          5            6          666         4000     0.427139     3.143078
--------------------------------------------------------------------------------
  Try 3

    Runtime 5.04e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            6          666         4000     0.165230     0.165230
```

1	6	666	4000	0.427139	1.088058
2	6	666	4000	0.626708	1.714766
3	6	666	4000	0.567855	2.282621
4	6	666	4000	0.497651	2.780272
5	6	666	4000	0.362806	3.143078

Try 4

Runtime 5.37e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	6	666	4000	0.165230	0.165230
1	6	666	4000	0.626708	1.287627
2	6	666	4000	0.567855	1.855481
3	6	666	4000	0.497651	2.353132
4	6	666	4000	0.427139	2.780272
5	6	666	4000	0.362806	3.143078

Try 5

Runtime 5.07e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	6	666	4000	0.165230	0.165230
1	6	666	4000	0.626708	1.287627
2	6	666	4000	0.567855	1.855481
3	6	666	4000	0.497651	2.353132
4	6	666	4000	0.427139	2.780272
5	6	666	4000	0.362806	3.143078

---

8 Cores CPU - Size Problem 2000

Try 1

Runtime 1.30e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	8	250	2000	0.124355	0.124355
1	8	250	2000	0.482495	0.979915
2	8	250	2000	0.455168	1.435083
3	8	250	2000	0.419508	1.854590
4	8	250	2000	0.379807	2.234397
5	8	250	2000	0.339607	2.574004
6	8	250	2000	0.301316	2.875320
7	8	250	2000	0.266273	3.141593

Try 2

Runtime 9.51e-06 [s]

Process	Total	problemSize	Total	Local	Total
0	8	250	2000	0.124355	0.124355
1	8	250	2000	0.482495	0.979915
2	8	250	2000	0.455168	1.435083
3	8	250	2000	0.419508	1.854590
4	8	250	2000	0.379807	2.234397
5	8	250	2000	0.339607	2.574004
6	8	250	2000	0.301316	2.875320
7	8	250	2000	0.266273	3.141593

Try 3

Runtime 4.50e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	8	250	2000	0.124355	0.124355
1	8	250	2000	0.379807	0.877227
2	8	250	2000	0.455168	1.332395
3	8	250	2000	0.301316	1.633710
4	8	250	2000	0.339607	1.973318
5	8	250	2000	0.482495	2.455812
6	8	250	2000	0.266273	2.722085

```
         7            8          250         2000     0.419508     3.141593
--------------------------------------------------------------------------------
  Try 4

    Runtime 4.95e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            8          250         2000     0.124355     0.124355
          1            8          250         2000     0.482495     0.979915
          2            8          250         2000     0.455168     1.435083
          3            8          250         2000     0.419508     1.854590
          4            8          250         2000     0.379807     2.234397
          5            8          250         2000     0.339607     2.574004
          6            8          250         2000     0.266273     2.840277
          7            8          250         2000     0.301316     3.141593
--------------------------------------------------------------------------------
  Try 5

    Runtime 6.11e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            8          250         2000     0.124355     0.124355
          1            8          250         2000     0.419508     0.916928
          2            8          250         2000     0.482495     1.399422
          3            8          250         2000     0.455168     1.854590
          4            8          250         2000     0.379807     2.234397
          5            8          250         2000     0.339607     2.574004
          6            8          250         2000     0.301316     2.875320
          7            8          250         2000     0.266273     3.141593
--------------------------------------------------------------------------------

 8 Cores CPU - Size Problem 4000

  Try 1

    Runtime 6.37e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            8          500         4000     0.124355     0.124355
          1            8          500         4000     0.379807     0.877227
          2            8          500         4000     0.482495     1.359721
          3            8          500         4000     0.455168     1.814890
          4            8          500         4000     0.419508     2.234397
          5            8          500         4000     0.339607     2.574004
          6            8          500         4000     0.301316     2.875320
          7            8          500         4000     0.266273     3.141593
--------------------------------------------------------------------------------
  Try 2

    Runtime 6.51e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            8          500         4000     0.124355     0.124355
          1            8          500         4000     0.379807     0.877227
          2            8          500         4000     0.482495     1.359721
          3            8          500         4000     0.455168     1.814890
          4            8          500         4000     0.419508     2.234397
          5            8          500         4000     0.339607     2.574004
          6            8          500         4000     0.301316     2.875320
          7            8          500         4000     0.266273     3.141593
--------------------------------------------------------------------------------
  Try 3

    Runtime 5.77e-05 [s]

    Process        Total  problemSize        Total        Local        Total
          0            8          500         4000     0.124355     0.124355
          1            8          500         4000     0.379807     0.877227
          2            8          500         4000     0.455168     1.332395
          3            8          500         4000     0.482495     1.814890
          4            8          500         4000     0.301316     2.116205
          5            8          500         4000     0.339607     2.455812
          6            8          500         4000     0.419508     2.875320
```

7	8	500	4000	0.266273	3.141593

Try 4

Runtime 5.92e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	8	500	4000	0.124355	0.124355
1	8	500	4000	0.455168	0.952588
2	8	500	4000	0.482495	1.435083
3	8	500	4000	0.419508	1.854590
4	8	500	4000	0.379807	2.234397
5	8	500	4000	0.339607	2.574004
6	8	500	4000	0.301316	2.875320
7	8	500	4000	0.266273	3.141593

Try 5

Runtime 5.81e-05 [s]

Process	Total	problemSize	Total	Local	Total
0	8	500	4000	0.124355	0.124355
1	8	500	4000	0.301316	0.798736
2	8	500	4000	0.455168	1.253904
3	8	500	4000	0.379807	1.633710
4	8	500	4000	0.419508	2.053218
5	8	500	4000	0.266273	2.319491
6	8	500	4000	0.339607	2.659098
7	8	500	4000	0.482495	3.141593
