

Assignment 5

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INFO6205 – Program Structures and Algorithms

Task:

- To implement a parallel sorting algorithm such that each partition of the array is sorted in parallel.

Conclusion:

After conducting experiments with various array sizes and a wide range of cutoff values, it was discovered that sorting the array takes less time when the cutoff value is near to half the array size.

Findings:

The experiment is carried out with four distinct huge array sizes and varied cut off values ranging from 20000 to 100000, as well as a variety of parallelism levels. The experiment values for each array size are listed below.

For each array size and cut off value the array is sorted 10 times and the time taken for ten time is displayed.

Degree of parallelism 2	Array Size = 2000000
cutoff : 20000	10times Time:1703ms
cutoff : 60000	10times Time:996ms
cutoff : 100000	10times Time:971ms
cutoff : 140000	10times Time:1420ms
cutoff : 180000	10times Time:1167ms
cutoff : 220000	10times Time:1213ms
cutoff : 260000	10times Time:1542ms
cutoff : 300000	10times Time:1252ms
cutoff : 340000	10times Time:1315ms
cutoff : 380000	10times Time:770ms
cutoff : 420000	10times Time:723ms
cutoff : 460000	10times Time:884ms
cutoff : 500000	10times Time:703ms
cutoff : 540000	10times Time:768ms
cutoff : 580000	10times Time:751ms
cutoff : 620000	10times Time:768ms
cutoff : 660000	10times Time:747ms
cutoff : 700000	10times Time:783ms
cutoff : 740000	10times Time:767ms

cutoff : 780000	10times Time:750ms
cutoff : 820000	10times Time:766ms
cutoff : 860000	10times Time:750ms
cutoff : 900000	10times Time:782ms
cutoff : 940000	10times Time:750ms
cutoff : 980000	10times Time:767ms

Degree of parallelism 2	Array Size = 2500000
cutoff : 20000	10times Time:1891ms
cutoff : 60000	10times Time:1197ms
cutoff : 100000	10times Time:1304ms
cutoff : 140000	10times Time:1420ms
cutoff : 180000	10times Time:1447ms
cutoff : 220000	10times Time:1595ms
cutoff : 260000	10times Time:1329ms
cutoff : 300000	10times Time:1060ms
cutoff : 340000	10times Time:878ms
cutoff : 380000	10times Time:894ms
cutoff : 420000	10times Time:1066ms
cutoff : 460000	10times Time:906ms
cutoff : 500000	10times Time:923ms
cutoff : 540000	10times Time:908ms
cutoff : 580000	10times Time:882ms
cutoff : 620000	10times Time:899ms

cutoff : 660000	10times Time:969ms
cutoff : 700000	10times Time:964ms
cutoff : 740000	10times Time:943ms
cutoff : 780000	10times Time:971ms
cutoff : 820000	10times Time:944ms
cutoff : 860000	10times Time:954ms
cutoff : 900000	10times Time:1000ms
cutoff : 940000	10times Time:954ms
cutoff : 980000	10times Time:953ms

Degree of parallelism 2	Array Size = 3000000
cutoff : 20000	10times Time:2652ms
cutoff : 60000	10times Time:1475ms
cutoff : 100000	10times Time:1763ms
cutoff : 140000	10times Time:1599ms
cutoff : 180000	10times Time:1805ms
cutoff : 220000	10times Time:1658ms
cutoff : 260000	10times Time:1779ms
cutoff : 300000	10times Time:1600ms
cutoff : 340000	10times Time:1546ms
cutoff : 380000	10times Time:1470ms
cutoff : 420000	10times Time:1572ms
cutoff : 460000	10times Time:1542ms

cutoff : 500000	10times Time:1482ms
cutoff : 540000	10times Time:1486ms
cutoff : 580000	10times Time:1497ms
cutoff : 620000	10times Time:1610ms
cutoff : 660000	10times Time:1649ms
cutoff : 700000	10times Time:1518ms
cutoff : 740000	10times Time:1437ms
cutoff : 780000	10times Time:1528ms
cutoff : 820000	10times Time:1550ms
cutoff : 860000	10times Time:1554ms
cutoff : 900000	10times Time:1529ms
cutoff : 940000	10times Time:1537ms
cutoff : 980000	10times Time:1554ms

Degree of parallelism 2	Array Size = 3500000
cutoff : 20000	10times Time:2789ms
cutoff : 60000	10times Time:1825ms
cutoff : 100000	10times Time:1938ms
cutoff : 140000	10times Time:2281ms
cutoff : 180000	10times Time:1569ms
cutoff : 220000	10times Time:1392ms
cutoff : 260000	10times Time:1178ms
cutoff : 300000	10times Time:1413ms
cutoff : 340000	10times Time:1212ms
cutoff : 380000	10times Time:1214ms

cutoff : 420000	10times Time:1218ms
cutoff : 460000	10times Time:1319ms
cutoff : 500000	10times Time:1338ms
cutoff : 540000	10times Time:1319ms
cutoff : 580000	10times Time:1361ms
cutoff : 620000	10times Time:1349ms
cutoff : 660000	10times Time:1316ms
cutoff : 700000	10times Time:1337ms
cutoff : 740000	10times Time:1317ms
cutoff : 780000	10times Time:1351ms
cutoff : 820000	10times Time:1287ms
cutoff : 860000	10times Time:1271ms
cutoff : 900000	10times Time:1358ms
cutoff : 940000	10times Time:1376ms
cutoff : 980000	10times Time:1705ms

Degree of parallelism 4	Array Size = 2000000
cutoff : 20000	10times Time:1799ms
cutoff : 60000	10times Time:942ms
cutoff : 100000	10times Time:967ms
cutoff : 140000	10times Time:1172ms
cutoff : 180000	10times Time:1118ms

cutoff : 220000	10times Time:1022ms
cutoff : 260000	10times Time:1260ms
cutoff : 300000	10times Time:1083ms
cutoff : 340000	10times Time:1018ms
cutoff : 380000	10times Time:1146ms
cutoff : 420000	10times Time:895ms
cutoff : 460000	10times Time:882ms
cutoff : 500000	10times Time:1163ms
cutoff : 540000	10times Time:834ms
cutoff : 580000	10times Time:847ms
cutoff : 620000	10times Time:853ms
cutoff : 660000	10times Time:824ms
cutoff : 700000	10times Time:849ms
cutoff : 740000	10times Time:826ms
cutoff : 780000	10times Time:818ms
cutoff : 820000	10times Time:853ms
cutoff : 860000	10times Time:861ms
cutoff : 900000	10times Time:1008ms
cutoff : 940000	10times Time:962ms
cutoff : 980000	10times Time:917ms

Degree of parallelism 4	Array Size = 2500000
cutoff : 20000	10times Time:2389ms
cutoff : 60000	10times Time:1130ms

cutoff : 100000	10times Time:1152ms
cutoff : 140000	10times Time:1507ms
cutoff : 180000	10times Time:1368ms
cutoff : 220000	10times Time:1488ms
cutoff : 260000	10times Time:949ms
cutoff : 300000	10times Time:888ms
cutoff : 340000	10times Time:817ms
cutoff : 380000	10times Time:840ms
cutoff : 420000	10times Time:923ms
cutoff : 460000	10times Time:946ms
cutoff : 500000	10times Time:852ms
cutoff : 540000	10times Time:885ms
cutoff : 580000	10times Time:850ms
cutoff : 620000	10times Time:848ms
cutoff : 660000	10times Time:802ms
cutoff : 700000	10times Time:816ms
cutoff : 740000	10times Time:783ms
cutoff : 780000	10times Time:796ms
cutoff : 820000	10times Time:779ms
cutoff : 860000	10times Time:782ms
cutoff : 900000	10times Time:765ms
cutoff : 940000	10times Time:769ms
cutoff : 980000	10times Time:752ms

Degree of parallelism 4**Array Size = 3000000**

cutoff : 20000	10times Time:2532ms
cutoff : 60000	10times Time:1393ms
cutoff : 100000	10times Time:1668ms
cutoff : 140000	10times Time:1642ms
cutoff : 180000	10times Time:1774ms
cutoff : 220000	10times Time:1471ms
cutoff : 260000	10times Time:1617ms
cutoff : 300000	10times Time:1322ms
cutoff : 340000	10times Time:1545ms
cutoff : 380000	10times Time:1925ms
cutoff : 420000	10times Time:1678ms
cutoff : 460000	10times Time:1576ms
cutoff : 500000	10times Time:1598ms
cutoff : 540000	10times Time:1645ms
cutoff : 580000	10times Time:1889ms
cutoff : 620000	10times Time:1520ms
cutoff : 660000	10times Time:1681ms
cutoff : 700000	10times Time:1489ms
cutoff : 740000	10times Time:1486ms
cutoff : 780000	10times Time:1480ms
cutoff : 820000	10times Time:1555ms
cutoff : 860000	10times Time:1543ms
cutoff : 900000	10times Time:1435ms
cutoff : 940000	10times Time:1293ms
cutoff : 980000	10times Time:1278ms

Degree of parallelism 4**Array Size = 3500000**

cutoff : 20000	10times Time:3039ms
cutoff : 60000	10times Time:1756ms
cutoff : 100000	10times Time:1886ms
cutoff : 140000	10times Time:2154ms
cutoff : 180000	10times Time:1834ms
cutoff : 220000	10times Time:1532ms
cutoff : 260000	10times Time:1087ms
cutoff : 300000	10times Time:1023ms
cutoff : 340000	10times Time:1139ms
cutoff : 380000	10times Time:1062ms
cutoff : 420000	10times Time:1040ms
cutoff : 460000	10times Time:1061ms
cutoff : 500000	10times Time:1064ms
cutoff : 540000	10times Time:1087ms
cutoff : 580000	10times Time:1061ms
cutoff : 620000	10times Time:1079ms
cutoff : 660000	10times Time:1094ms
cutoff : 700000	10times Time:1064ms
cutoff : 740000	10times Time:1067ms
cutoff : 780000	10times Time:1080ms
cutoff : 820000	10times Time:1081ms
cutoff : 860000	10times Time:1083ms
cutoff : 900000	10times Time:1016ms
cutoff : 940000	10times Time:1039ms

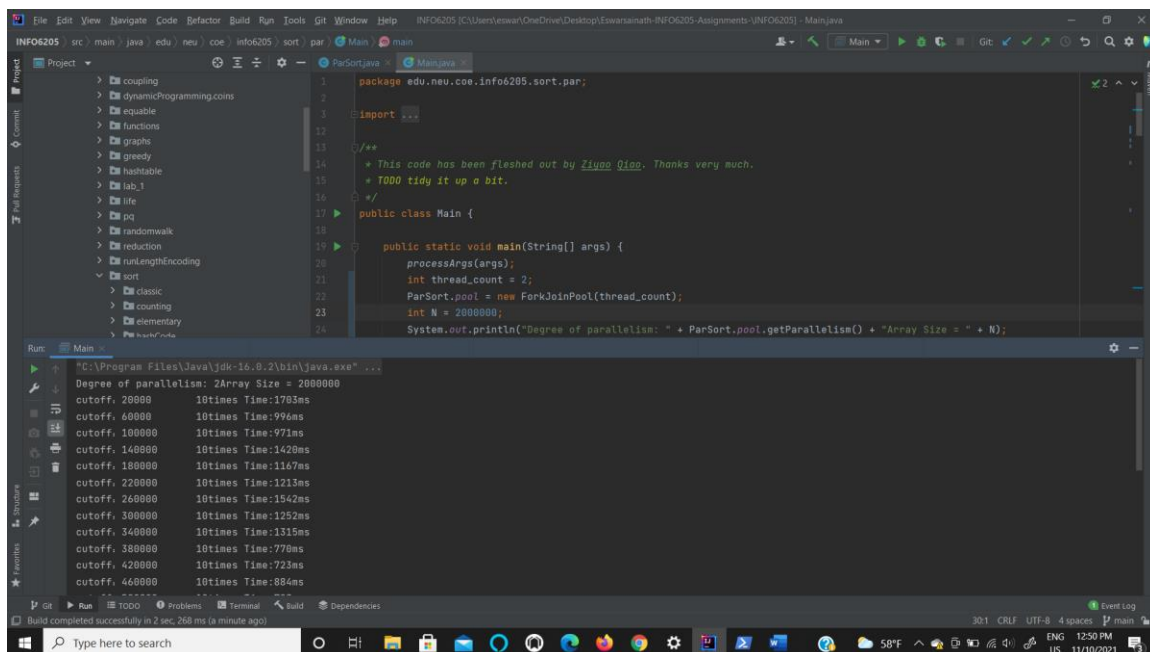
cutoff : 980000

10times Time:1086ms

Output Screenshot:

Degree of parallelism 2

Array Size = 2000000



The screenshot shows an IDE with a Java project. The code in the editor is as follows:

```
package edu.neu.coe.info6205.sort.par;

import java.util.concurrent.ForkJoinPool;

/**
 * This code has been fleshed out by Ziyao Qiao. Thanks very much.
 * TODO tidy it up a bit.
 */
public class Main {

    public static void main(String[] args) {
        processArgs(args);
        int thread_count = 2;
        ParSort.pool = new ForkJoinPool(thread_count);
        int N = 2000000;
        System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + " Array Size = " + N);
    }
}
```

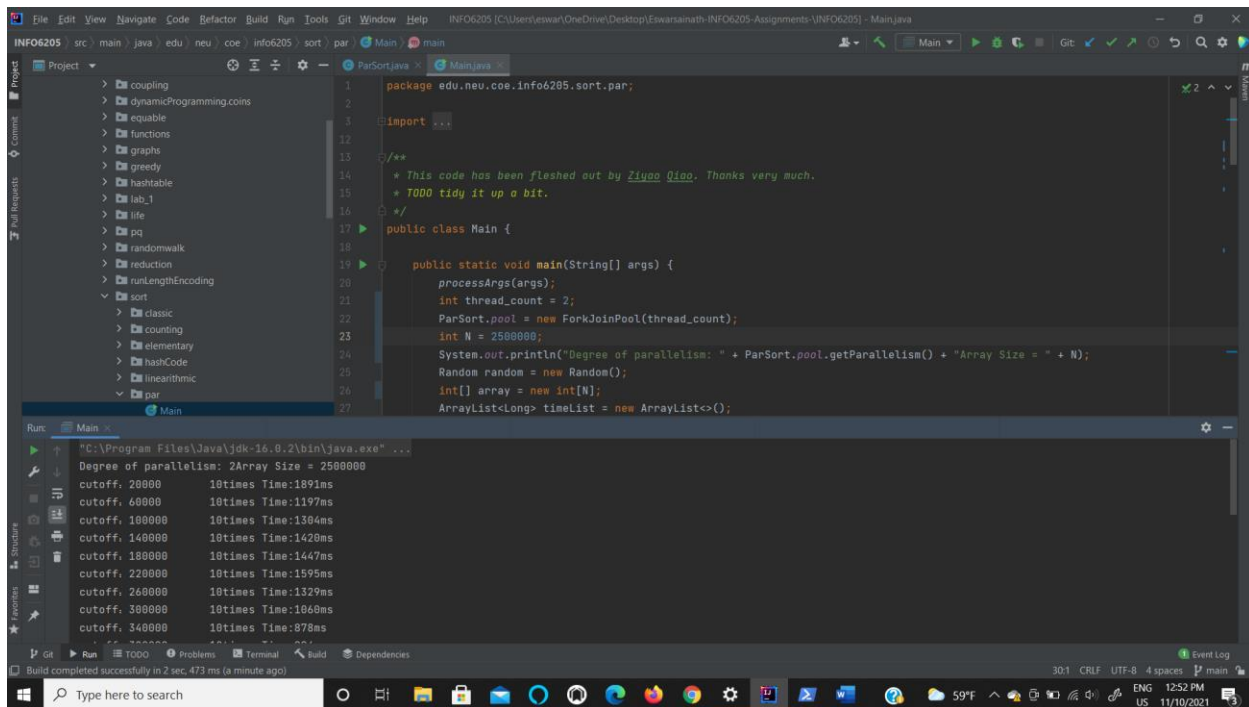
The output window shows the following results:

```
Run: Main
C:\Program Files\Java\jdk-16.0.2\bin\java.exe
Degree of parallelism: 2 Array Size = 2000000
cutoff: 200000 10times Time:1703ms
cutoff: 400000 10times Time:596ms
cutoff: 1000000 10times Time:571ms
cutoff: 1400000 10times Time:1420ms
cutoff: 1800000 10times Time:1167ms
cutoff: 2200000 10times Time:1213ms
cutoff: 2600000 10times Time:1542ms
cutoff: 3000000 10times Time:1252ms
cutoff: 3400000 10times Time:1315ms
cutoff: 3800000 10times Time:770ms
cutoff: 4200000 10times Time:723ms
cutoff: 4600000 10times Time:884ms
```

The IDE status bar at the bottom indicates "Build completed successfully in 2 sec, 260 ms (a minute ago)".

Degree of parallelism 2

Array Size = 2500000



```
package edu.neu.coe.info6205.sort.par;

import ...

/**
 * This code has been fleshed out by Ziyao Qiao. Thanks very much.
 * TODO tidy it up a bit.
 */
public class Main {

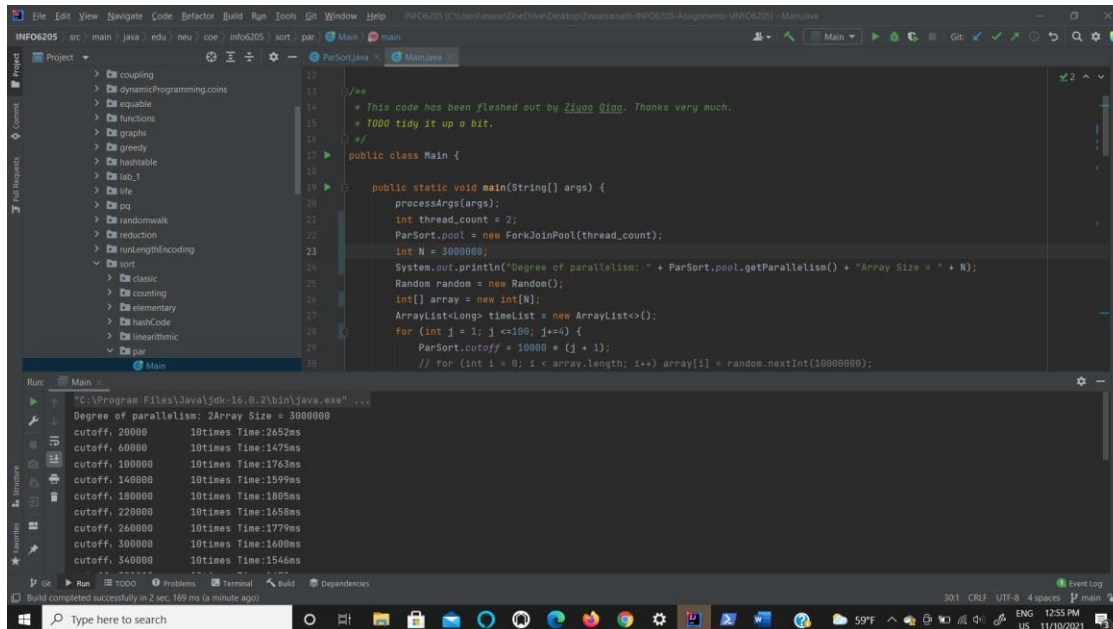
    public static void main(String[] args) {
        processArgs(args);
        int thread_count = 2;
        ParSort.pool = new ForkJoinPool(thread_count);
        int N = 2500000;
        System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + "Array Size = " + N);
        Random random = new Random();
        int[] array = new int[N];
        ArrayList<Long> timelist = new ArrayList<>();
    }
}
```

Run: Main

```
"C:\Program Files\Java\jdk-16.0.2\bin\java.exe" ...
Degree of parallelism: 2Array Size = 2500000
cutoff, 20000      10times Time:1891ms
cutoff, 40000      10times Time:1197ms
cutoff, 100000     10times Time:1304ms
cutoff, 140000     10times Time:1428ms
cutoff, 180000     10times Time:1447ms
cutoff, 220000     10times Time:1595ms
cutoff, 260000     10times Time:1329ms
cutoff, 300000     10times Time:1869ms
cutoff, 340000     10times Time:878ms
```

Degree of parallelism 2

Array Size = 3000000



```
package edu.neu.coe.info6205.sort.par;

import ...

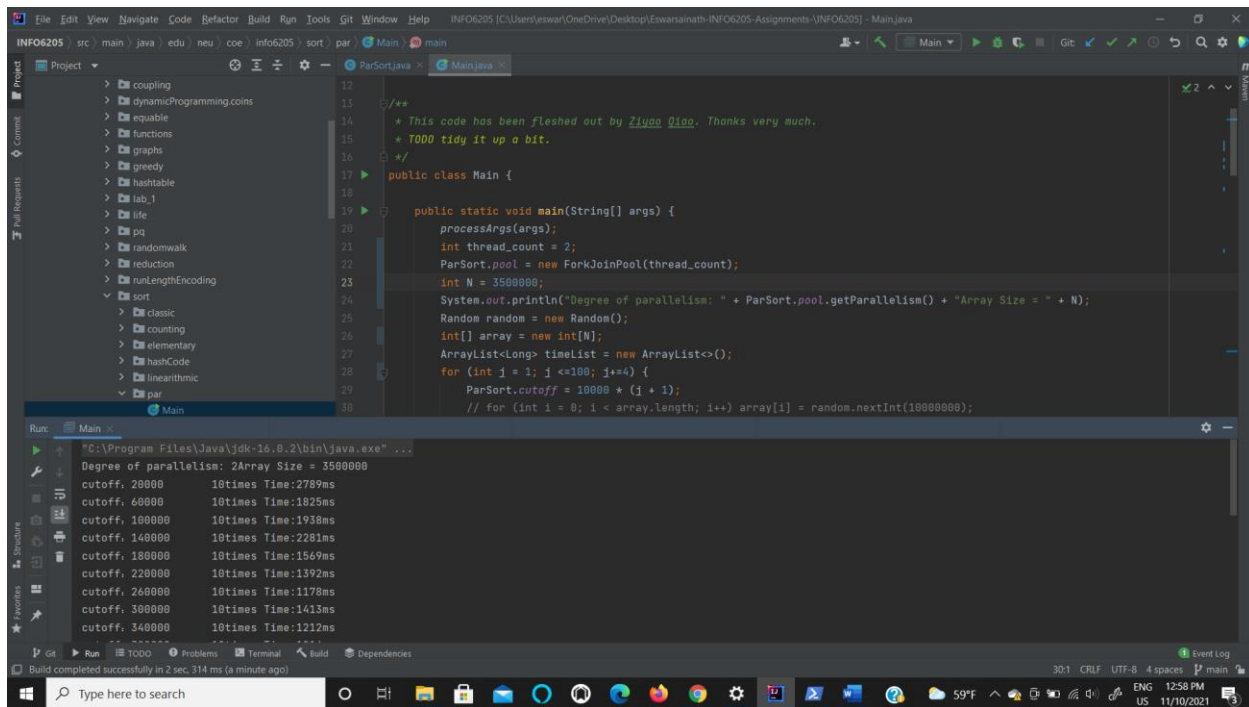
/**
 * This code has been fleshed out by Ziyao Qiao. Thanks very much.
 * TODO tidy it up a bit.
 */
public class Main {

    public static void main(String[] args) {
        processArgs(args);
        int thread_count = 2;
        ParSort.pool = new ForkJoinPool(thread_count);
        int N = 3000000;
        System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + "Array Size = " + N);
        Random random = new Random();
        int[] array = new int[N];
        ArrayList<Long> timelist = new ArrayList<>();
        for (int j = 1; j <= 100; j++) {
            ParSort.cutoff = 10000 * (j + 1);
            // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(10000000);
        }
    }
}
```

Run: Main

```
"C:\Program Files\Java\jdk-16.0.2\bin\java.exe" ...
Degree of parallelism: 2Array Size = 3000000
cutoff, 20000      10times Time:2652ms
cutoff, 40000      10times Time:1475ms
cutoff, 100000     10times Time:1763ms
cutoff, 140000     10times Time:1599ms
cutoff, 180000     10times Time:1805ms
cutoff, 220000     10times Time:1658ms
cutoff, 260000     10times Time:1779ms
cutoff, 300000     10times Time:1608ms
cutoff, 340000     10times Time:1546ms
```

Degree of parallelism 2 Array Size = 3500000



```
12
13
14  * This code has been fleshed out by Zijun Qiao. Thanks very much.
15  * TOOO tidy it up a bit.
16  */
17  public class Main {
18
19      public static void main(String[] args) {
20          processArgs(args);
21          int thread_count = 2;
22          ParSort.pool = new ForkJoinPool(thread_count);
23          int N = 3500000;
24          System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + " Array Size = " + N);
25          Random random = new Random();
26          int[] array = new int[N];
27          ArrayList<Long> timeList = new ArrayList<>();
28          for (int j = 1; j <= 100; j++) {
29              ParSort.cutoff = 10000 * (j + 1);
30              // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(10000000);
31          }
32      }
33  }
```

Run: Main x

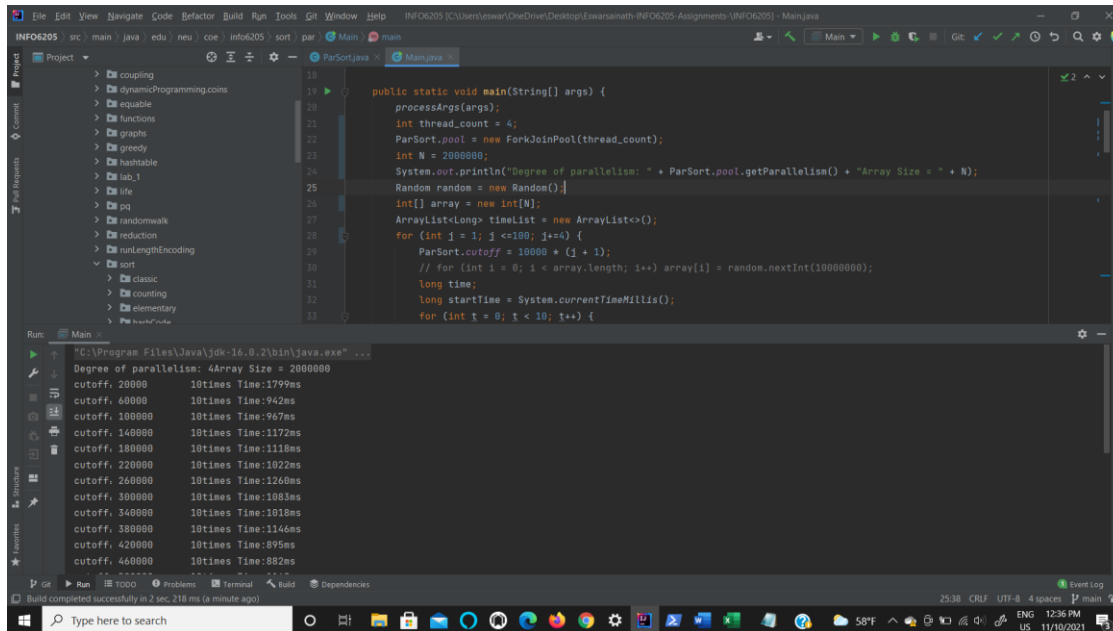
"C:\Program Files\Java\jdk-16.0.2\bin\java.exe" ...

Degree of parallelism: 2 Array Size = 3500000

cutoff	10times Time
20000	2789ms
40000	1825ms
60000	1938ms
80000	2281ms
100000	1569ms
120000	1392ms
140000	1178ms
160000	1413ms
180000	1212ms

Build completed successfully in 2 sec, 314 ms (a minute ago)

Degree of parallelism 4 Array Size = 2000000



```
18
19  public static void main(String[] args) {
20      processArgs(args);
21      int thread_count = 4;
22      ParSort.pool = new ForkJoinPool(thread_count);
23      int N = 2000000;
24      System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + " Array Size = " + N);
25      Random random = new Random();
26      int[] array = new int[N];
27      ArrayList<Long> timeList = new ArrayList<>();
28      for (int j = 1; j <= 100; j++) {
29          ParSort.cutoff = 10000 * (j + 1);
30          // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(10000000);
31          long time;
32          long startTime = System.currentTimeMillis();
33          for (int t = 0; t < 10; t++) {
34              // ...
35          }
36      }
37  }
```

Run: Main x

"C:\Program Files\Java\jdk-16.0.2\bin\java.exe" ...

Degree of parallelism: 4 Array Size = 2000000

cutoff	10times Time
20000	1797ms
40000	942ms
60000	967ms
80000	1177ms
100000	1118ms
120000	1022ms
140000	1260ms
160000	1083ms
180000	1018ms
200000	1146ms
220000	895ms
240000	882ms

Build completed successfully in 2 sec, 218 ms (a minute ago)

Degree of parallelism 4 Array Size = 2500000

```
public static void main(String[] args) {
    processArgs(args);
    int thread_count = 4;
    ParSort.pool = new ForkJoinPool(thread_count);
    int N = 2500000;
    System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + " Array Size = " + N);
    Random random = new Random();
    int[] array = new int[N];
    ArrayList<Long> timeList = new ArrayList<>();
    for (int j = 1; j <= 100; j+=4) {
        ParSort.cutoff = 10000 * (j + 1);
        // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(10000000);
        long time;
        long startTime = System.currentTimeMillis();
        for (int t = 0; t < 10; t++) {
```

Run: Main

```
C:\Program Files\Java\jdk-16.0.2\bin\java.exe ...
Degree of parallelism: 4 Array Size = 2500000
cutoff, 20000      10times Time:2389ms
cutoff, 60000      10times Time:1130ms
cutoff, 100000     10times Time:1152ms
cutoff, 140000     10times Time:1507ms
cutoff, 180000     10times Time:1368ms
cutoff, 220000     10times Time:1488ms
cutoff, 260000     10times Time:949ms
cutoff, 300000     10times Time:888ms
cutoff, 340000     10times Time:817ms
cutoff, 380000     10times Time:840ms
cutoff, 420000     10times Time:923ms
cutoff, 460000     10times Time:946ms
```

Build completed successfully in 2 sec. 50 ms (a minute ago)

Degree of parallelism 4 Array Size = 3000000

```
public static void main(String[] args) {
    processArgs(args);
    int thread_count = 4;
    ParSort.pool = new ForkJoinPool(thread_count);
    int N = 3000000;
    System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + " Array Size = " + N);
    Random random = new Random();
    int[] array = new int[N];
    ArrayList<Long> timeList = new ArrayList<>();
    for (int j = 1; j <= 100; j+=4) {
        ParSort.cutoff = 10000 * (j + 1);
        // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(10000000);
        long time;
        long startTime = System.currentTimeMillis();
        for (int t = 0; t < 10; t++) {
```

Run: Main

```
C:\Program Files\Java\jdk-16.0.2\bin\java.exe ...
Degree of parallelism: 4 Array Size = 3000000
cutoff, 20000      10times Time:2532ms
cutoff, 60000      10times Time:1393ms
cutoff, 100000     10times Time:1668ms
cutoff, 140000     10times Time:1642ms
cutoff, 180000     10times Time:1774ms
cutoff, 220000     10times Time:1471ms
cutoff, 260000     10times Time:1617ms
cutoff, 300000     10times Time:1322ms
cutoff, 340000     10times Time:1545ms
cutoff, 380000     10times Time:1925ms
cutoff, 420000     10times Time:1678ms
cutoff, 460000     10times Time:1576ms
```

Build completed successfully in 2 sec. 251 ms (a minute ago)

Degree of parallelism 4

Array Size = 3500000

The screenshot shows an IDE with a Java project named 'INFO6205'. The main file, 'Main.java', contains the following code:

```
public static void main(String[] args) {
    processArgs(args);
    int thread_count = 4;
    ParSort.pool = new ForkJoinPool(thread_count);
    int N = 3500000;
    System.out.println("Degree of parallelism: " + ParSort.pool.getParallelism() + " Array Size = " + N);
    Random random = new Random();
    int[] array = new int[N];
    ArrayList<Long> timeList = new ArrayList<>();
    for (int j = 1; j <= 100; j+=4) {
        ParSort.cutoff = 10000 * (j + 1);
        // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(100000000);
        long time;
        long startTime = System.currentTimeMillis();
        for (int t = 0; t < 10; t++) {
```

The Run console shows the output of the program:

```
"C:\Program Files\Java\jdk-16.0.2\bin\java.exe" ...
Degree of parallelism: 4 Array Size = 3500000
cutoff, 20000      10times Time:1039ms
cutoff, 60000      10times Time:1756ms
cutoff, 100000     10times Time:1886ms
cutoff, 140000     10times Time:2154ms
cutoff, 180000     10times Time:1834ms
cutoff, 220000     10times Time:1532ms
cutoff, 260000     10times Time:1087ms
cutoff, 300000     10times Time:1023ms
cutoff, 340000     10times Time:1139ms
cutoff, 380000     10times Time:1062ms
cutoff, 420000     10times Time:1040ms
cutoff, 460000     10times Time:1061ms
```

The status bar at the bottom indicates the build completed successfully in 2 sec, 388 ms (a minute ago). The system tray shows the date as 11/10/2021 and time as 12:47 PM.