

Program Structure and Algorithms

Assignment - 4 Parallel Sort

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TASK:

1. A cutoff (defaults to, say, 1000) which you will update according to the first argument in the command line when running. It's your job to experiment and come up with a good value for this cutoff. If there are fewer elements to sort than the cutoff, then you should use the system sort instead.
2. Recursion depth or the number of available threads. Using this determination, you might decide on an ideal number (t) of separate threads (stick to powers of 2) and arrange for that number of partitions to be parallelized (by preventing recursion after the depth of $\lg t$ is reached).
3. An appropriate combination of these.

CONCLUSION:

We can easily say that four threads would be a good choice and using any thread beyond them would be useless and wastage of resources.

For number of threads(T) and recursion depth(d), we can easily deduce that:

$$T = 2^d$$

Or the maximum recursion depth would be

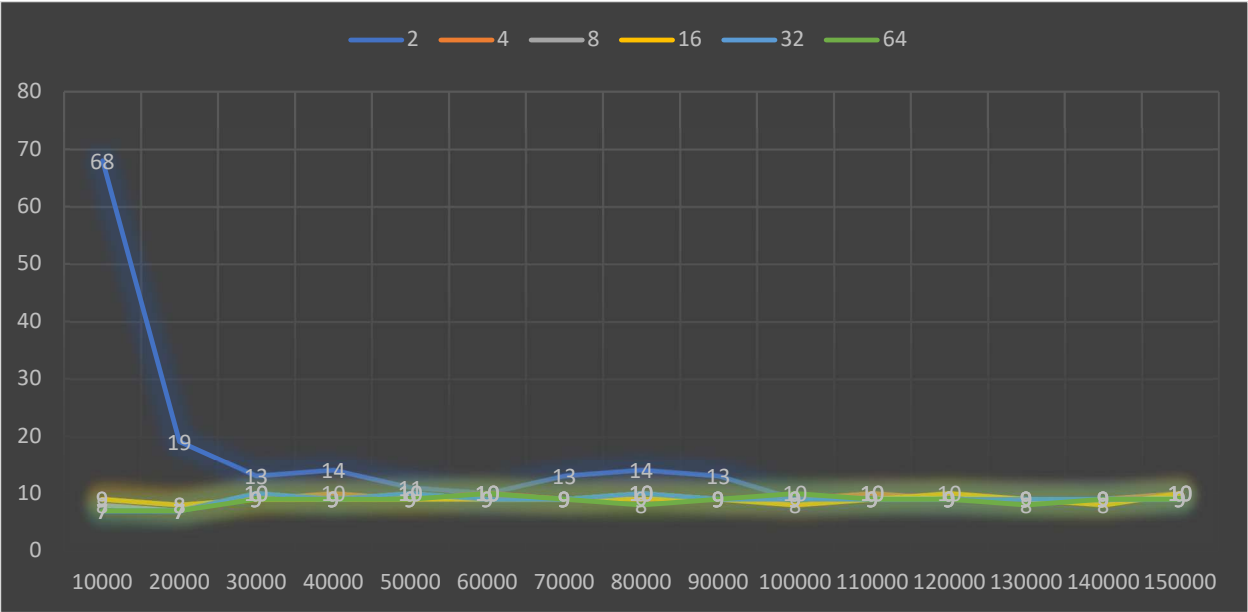
$$\lg(\text{size of array/cutoff})$$

At any moment, the depth will not be more than maximum depth as array reaches the cutoff.

EVIDENCE:

Array Size = 20000

	Threads					
cutoff	2	4	8	16	32	64
10000	68	9	8	9	7	7
20000	19	8	7	8	7	7
30000	13	9	10	9	10	9
40000	14	10	9	9	9	9
50000	11	9	10	9	10	9
60000	10	10	9	9	9	10
70000	13	9	9	9	9	9
80000	14	10	10	9	10	8
90000	13	9	9	9	9	9
100000	9	9	9	8	9	10
110000	10	10	9	9	9	9
120000	9	9	9	10	9	9
130000	9	9	9	9	9	8
140000	9	9	9	8	9	9
150000	10	10	9	10	9	9

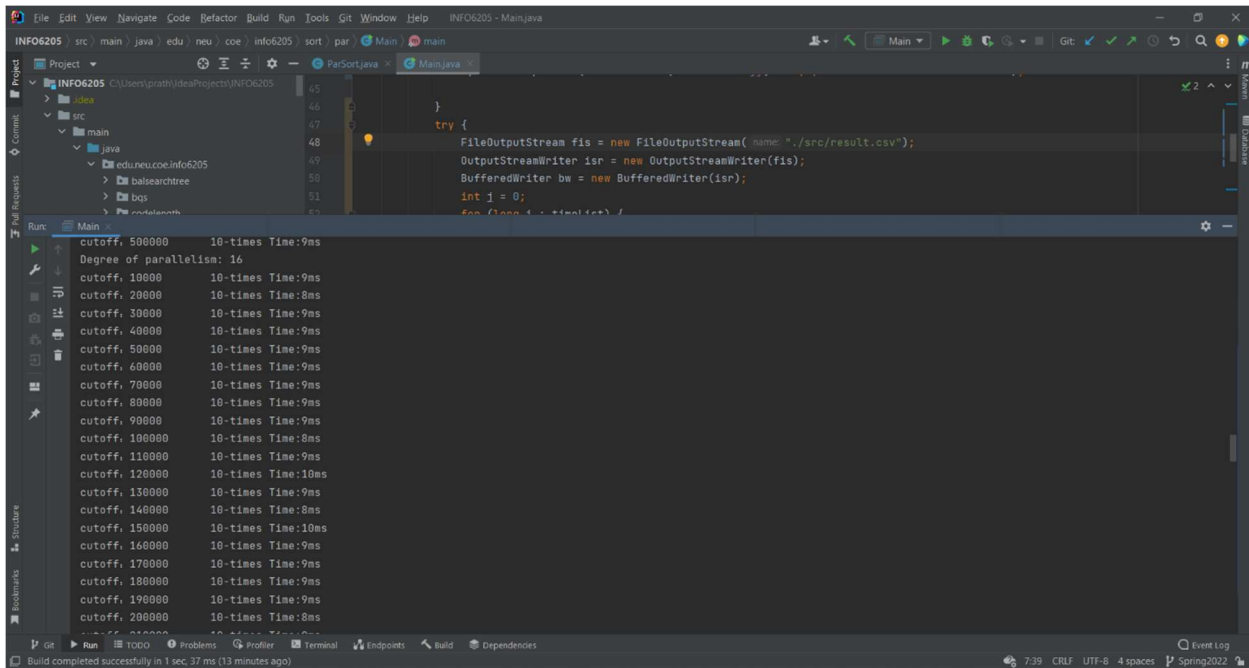
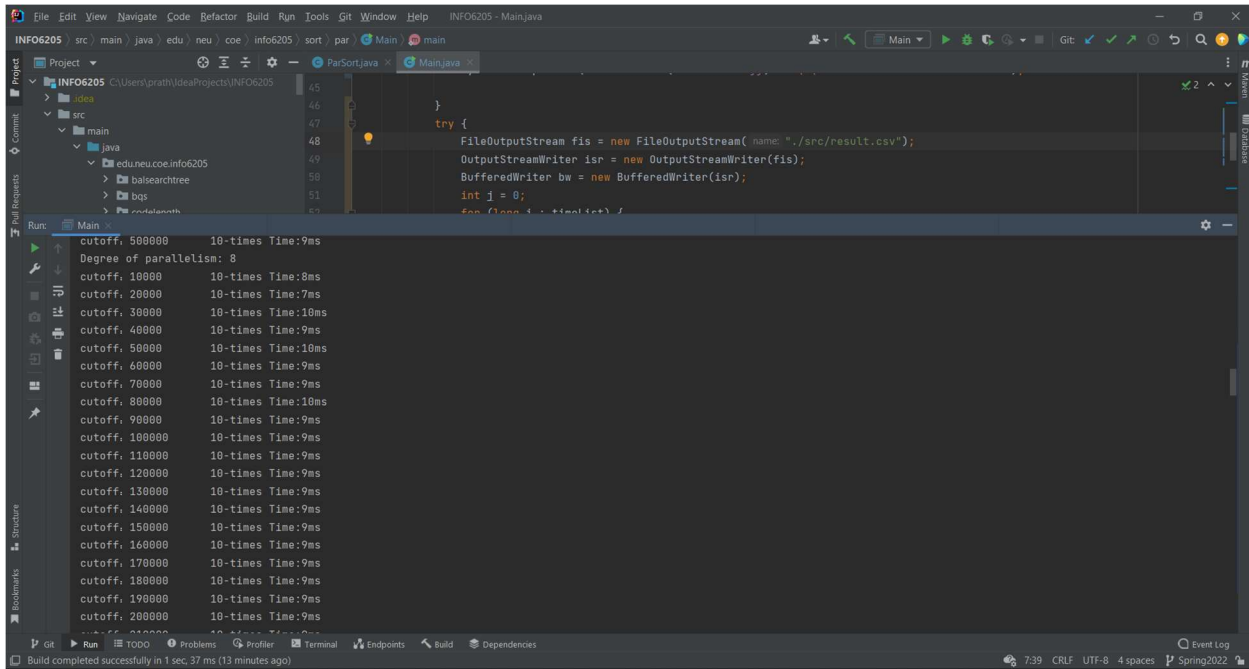


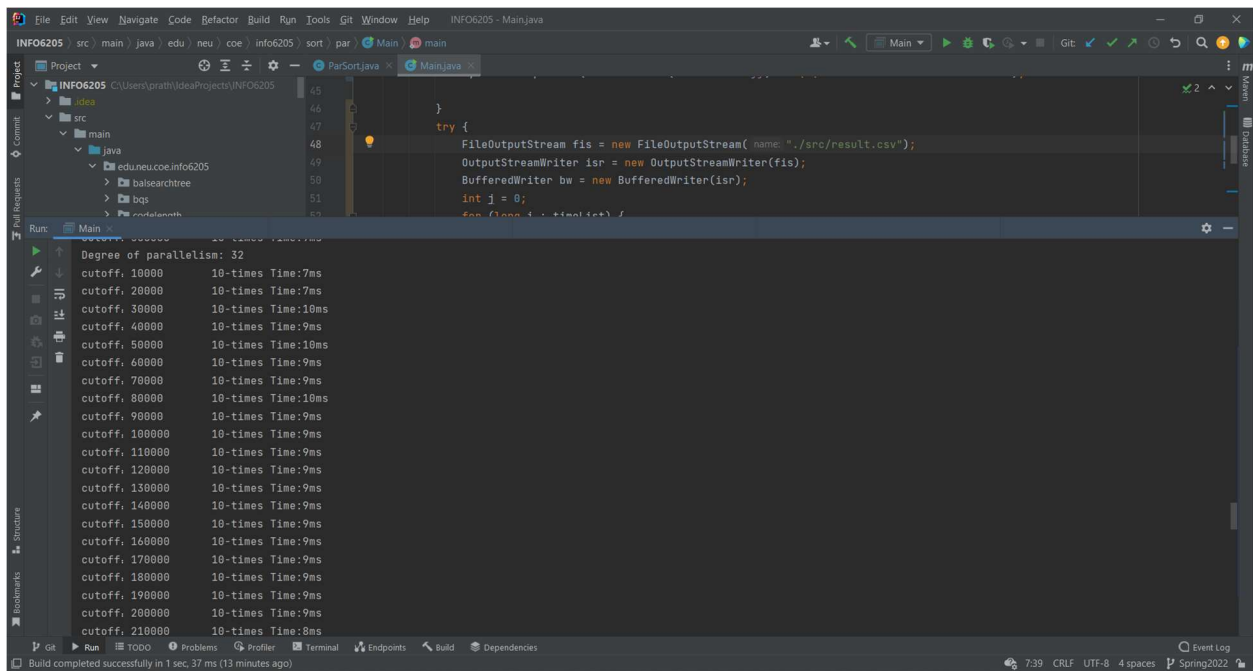
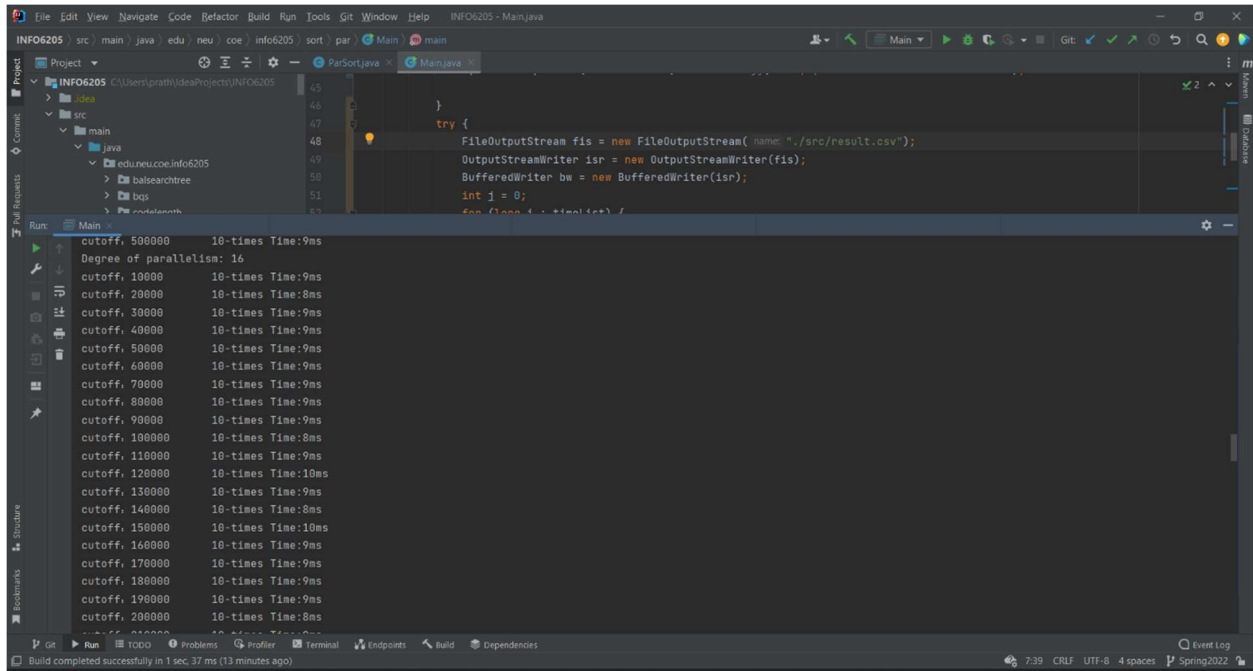
The screenshot shows the IntelliJ IDEA interface with a project named 'INFO6205'. The 'Main.java' file is open, displaying a Java program that calculates the time taken to process an array of size 20000 with a degree of parallelism of 2. The 'Run' console shows the output of the program, which includes the size of the array, the degree of parallelism, and a list of cutoff values and their corresponding times.

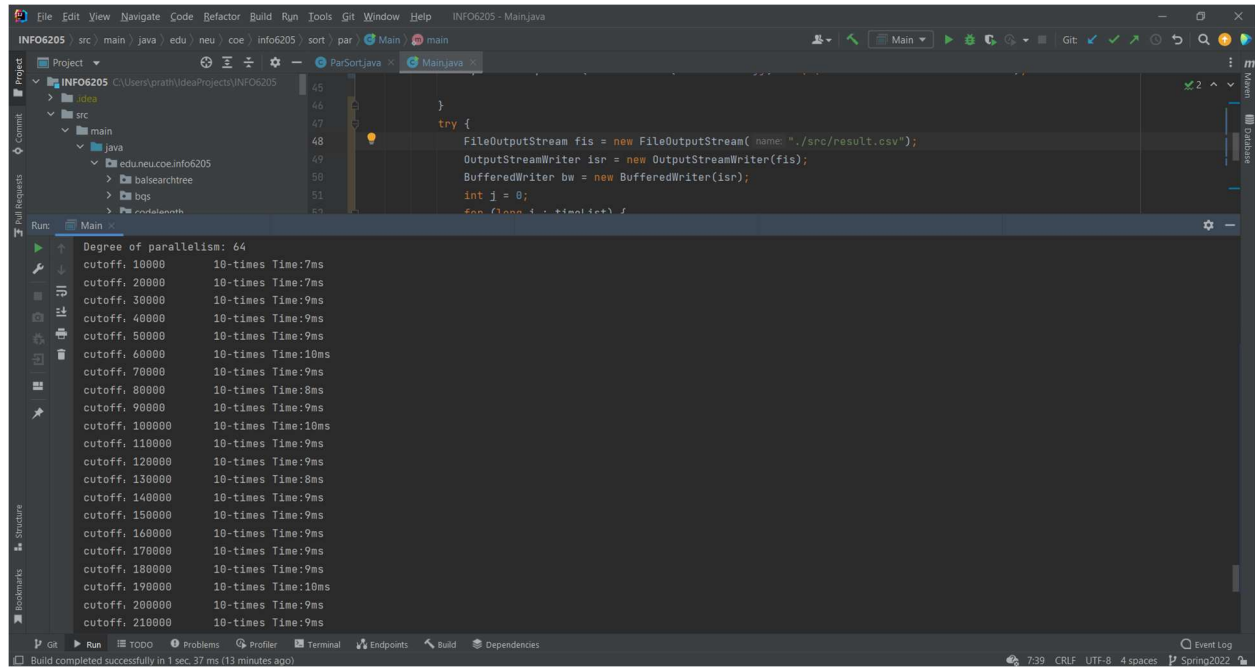
```
INFO6205 [src > main > java > edu > neu > coe > info6205 > sort > par > Main] Main
C:\Program Files\Java\jdk-17.0.1\bin\java.exe ...
Size of Array is:20000
Degree of parallelism: 2
cutoff, 10000      10-times Time:68ms
cutoff, 20000      10-times Time:19ms
cutoff, 30000      10-times Time:13ms
cutoff, 40000      10-times Time:14ms
cutoff, 50000      10-times Time:11ms
cutoff, 60000      10-times Time:18ms
cutoff, 70000      10-times Time:13ms
cutoff, 80000      10-times Time:14ms
cutoff, 90000      10-times Time:13ms
cutoff, 100000     10-times Time:9ms
cutoff, 110000     10-times Time:10ms
cutoff, 120000     10-times Time:9ms
cutoff, 130000     10-times Time:9ms
cutoff, 140000     10-times Time:9ms
cutoff, 150000     10-times Time:10ms
cutoff, 160000     10-times Time:9ms
cutoff, 170000     10-times Time:10ms
cutoff, 180000     10-times Time:10ms
cutoff, 190000     10-times Time:10ms
```

The screenshot shows the IntelliJ IDEA interface with the same project 'INFO6205'. The 'Main.java' file is open, displaying a Java program that calculates the time taken to process an array of size 20000 with a degree of parallelism of 4. The 'Run' console shows the output of the program, which includes the size of the array, the degree of parallelism, and a list of cutoff values and their corresponding times.

```
INFO6205 [src > main > java > edu > neu > coe > info6205 > sort > par > Main] Main
Cutoff, 490000     10-times Time:9ms
cutoff, 500000     10-times Time:8ms
Degree of parallelism: 4
cutoff, 10000      10-times Time:9ms
cutoff, 20000      10-times Time:8ms
cutoff, 30000      10-times Time:9ms
cutoff, 40000      10-times Time:10ms
cutoff, 50000      10-times Time:9ms
cutoff, 60000      10-times Time:10ms
cutoff, 70000      10-times Time:9ms
cutoff, 80000      10-times Time:10ms
cutoff, 90000      10-times Time:9ms
cutoff, 100000     10-times Time:9ms
cutoff, 110000     10-times Time:10ms
cutoff, 120000     10-times Time:9ms
cutoff, 130000     10-times Time:9ms
cutoff, 140000     10-times Time:10ms
cutoff, 150000     10-times Time:9ms
cutoff, 160000     10-times Time:9ms
cutoff, 170000     10-times Time:8ms
cutoff, 180000     10-times Time:10ms
cutoff, 190000     10-times Time:9ms
```







Array Size = 40000

cutoff	Threads					
	2	4	8	16	32	64
10000	108	14	15	12	13	13
20000	15	12	11	11	13	11
30000	16	16	14	15	15	15
40000	15	15	14	14	15	15
50000	20	20	20	20	20	20
60000	21	21	19	19	19	20
70000	20	20	19	19	18	19
80000	19	19	19	19	19	19
90000	21	19	20	18	20	19
100000	23	19	18	18	19	19
110000	24	19	19	19	19	19
120000	23	19	19	19	19	19
130000	29	18	19	20	19	20
140000	26	19	20	19	18	18
150000	23	20	19	18	19	20

The screenshot shows the IntelliJ IDEA interface with a project named 'INFO6205'. The code editor displays a Java file 'Main.java' with the following content:

```
14  * This code has been fleshed out by Ziyao Qiao. Thanks very much.
15  * TODO tidy it up a bit.
16  */
17  public class Main {
18
19      public static void main(String[] args) {
```

The Run window shows the execution output for 'Main' with a 'Degree of parallelism: 8'. The output consists of a list of cutoff values and their corresponding execution times:

Cutoff	Execution Time
490000	10-times Time:19ms
500000	10-times Time:20ms
100000	10-times Time:15ms
200000	10-times Time:11ms
300000	10-times Time:14ms
400000	10-times Time:14ms
500000	10-times Time:20ms
600000	10-times Time:19ms
700000	10-times Time:19ms
800000	10-times Time:19ms
900000	10-times Time:20ms
1000000	10-times Time:18ms
1100000	10-times Time:19ms
1200000	10-times Time:19ms
1300000	10-times Time:19ms
1400000	10-times Time:20ms
1500000	10-times Time:19ms
1600000	10-times Time:19ms
1700000	10-times Time:19ms
1800000	10-times Time:20ms
1900000	10-times Time:19ms
2000000	10-times Time:20ms
2100000	10-times Time:20ms

The status bar at the bottom indicates 'Build completed successfully in 1 sec, 13 ms (a minute ago)'.

The screenshot shows the IntelliJ IDEA interface with the same project 'INFO6205'. The code editor displays the same 'Main.java' file as in the first screenshot.

The Run window shows the execution output for 'Main' with a 'Degree of parallelism: 4'. The output consists of a list of cutoff values and their corresponding execution times:

Cutoff	Execution Time
490000	10-times Time:18ms
500000	10-times Time:19ms
100000	10-times Time:14ms
200000	10-times Time:12ms
300000	10-times Time:16ms
400000	10-times Time:15ms
500000	10-times Time:20ms
600000	10-times Time:21ms
700000	10-times Time:20ms
800000	10-times Time:19ms
900000	10-times Time:19ms
1000000	10-times Time:19ms
1100000	10-times Time:19ms
1200000	10-times Time:19ms
1300000	10-times Time:18ms
1400000	10-times Time:19ms
1500000	10-times Time:20ms
1600000	10-times Time:19ms
1700000	10-times Time:19ms
1800000	10-times Time:19ms
1900000	10-times Time:19ms
2000000	10-times Time:20ms
2100000	10-times Time:20ms

The status bar at the bottom indicates 'Build completed successfully in 1 sec, 13 ms (moments ago)'.

INFO6205 - Main.java

```
14 * This code has been fleshed out by Ziyao Qiao. Thanks very much.
15 * TODO tidy it up a bit.
16 */
17 public class Main {
18
19     public static void main(String[] args) {
```

Run: Main

cutoff	10-times Time
400000	10-times Time:19ms
490000	10-times Time:19ms
500000	10-times Time:19ms
Degree of parallelism: 16	
10000	10-times Time:12ms
20000	10-times Time:11ms
30000	10-times Time:15ms
40000	10-times Time:14ms
50000	10-times Time:20ms
60000	10-times Time:19ms
70000	10-times Time:19ms
80000	10-times Time:19ms
90000	10-times Time:18ms
100000	10-times Time:18ms
110000	10-times Time:19ms
120000	10-times Time:19ms
130000	10-times Time:20ms
140000	10-times Time:19ms
150000	10-times Time:18ms
160000	10-times Time:20ms
170000	10-times Time:19ms
180000	10-times Time:19ms
190000	10-times Time:20ms
200000	10-times Time:20ms
210000	10-times Time:20ms

Build completed successfully in 1 sec, 13 ms (a minute ago)

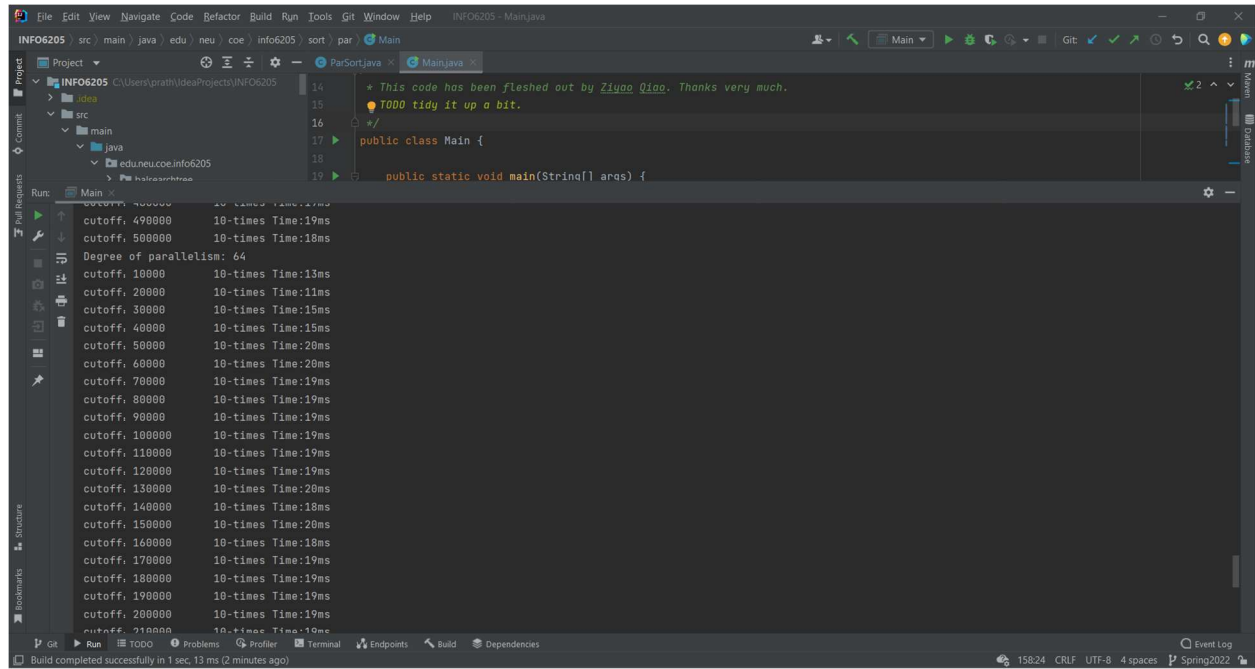
INFO6205 - Main.java

```
14 * This code has been fleshed out by Ziyao Qiao. Thanks very much.
15 * TODO tidy it up a bit.
16 */
17 public class Main {
18
19     public static void main(String[] args) {
```

Run: Main

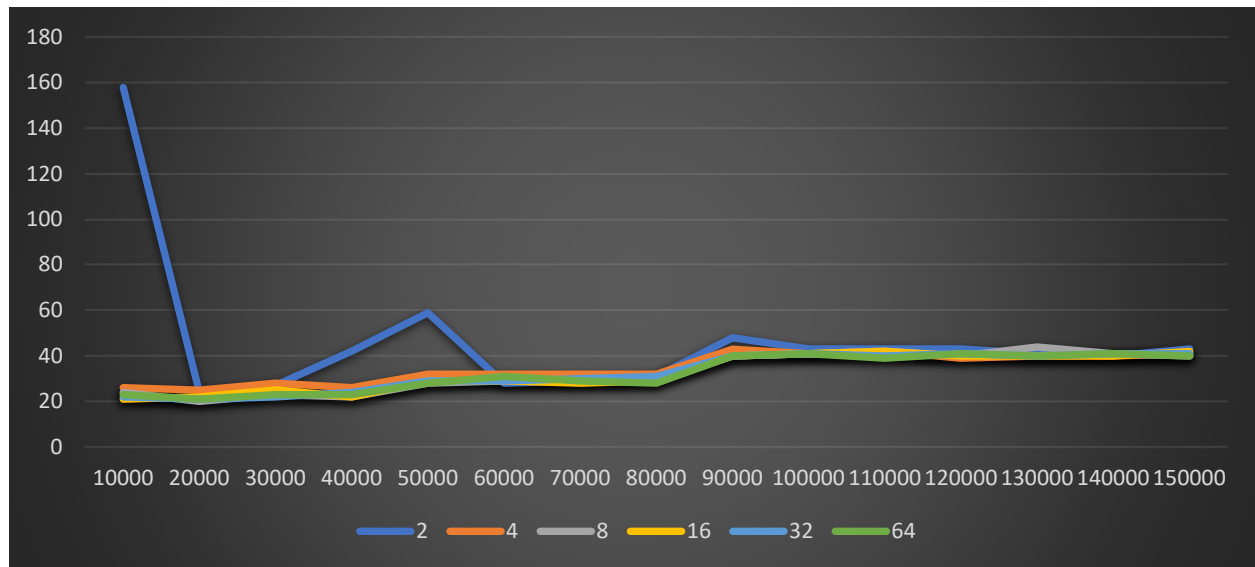
cutoff	10-times Time
400000	10-times Time:20ms
490000	10-times Time:20ms
500000	10-times Time:19ms
Degree of parallelism: 32	
10000	10-times Time:13ms
20000	10-times Time:13ms
30000	10-times Time:15ms
40000	10-times Time:15ms
50000	10-times Time:20ms
60000	10-times Time:19ms
70000	10-times Time:18ms
80000	10-times Time:19ms
90000	10-times Time:20ms
100000	10-times Time:19ms
110000	10-times Time:19ms
120000	10-times Time:19ms
130000	10-times Time:19ms
140000	10-times Time:18ms
150000	10-times Time:19ms
160000	10-times Time:19ms
170000	10-times Time:19ms
180000	10-times Time:19ms
190000	10-times Time:19ms
200000	10-times Time:19ms
210000	10-times Time:19ms

Build completed successfully in 1 sec, 13 ms (a minute ago)



Array Size = 80000

cutoff	Threads					
	2	4	8	16	32	64
10000	158	26	24	21	22	23
20000	24	25	20	22	21	21
30000	27	28	23	25	22	23
40000	42	26	22	22	24	23
50000	59	32	28	29	29	28
60000	28	32	29	29	29	31
70000	29	32	29	28	30	29
80000	31	32	29	29	31	28
90000	48	43	40	40	40	40
100000	43	41	41	41	41	41
110000	43	42	42	42	40	39
120000	43	39	40	40	41	41
130000	41	40	44	40	40	40
140000	40	40	41	40	41	41
150000	43	41	40	42	41	40



```
File Edit View Navigate Code Refactor Build Run Tools Git Window Help INFO6205 - Main.java
INFO6205 src main java edu neu coe info6205 sort par Main
Project Project
INFO6205 C:\Users\prath\IdeaProjects\INFO6205
src
Run: Main
C:\Program Files\Java\jdk-17.0.1\bin\java.exe ...
Size of Array is:80000
Degree of parallelism: 2
cutoff, 10000 10-times Time:158ms
cutoff, 20000 10-times Time:24ms
cutoff, 30000 10-times Time:27ms
cutoff, 40000 10-times Time:42ms
cutoff, 50000 10-times Time:59ms
cutoff, 60000 10-times Time:28ms
cutoff, 70000 10-times Time:29ms
cutoff, 80000 10-times Time:31ms
cutoff, 90000 10-times Time:48ms
cutoff, 100000 10-times Time:43ms
cutoff, 110000 10-times Time:43ms
cutoff, 120000 10-times Time:43ms
cutoff, 130000 10-times Time:41ms
cutoff, 140000 10-times Time:40ms
cutoff, 150000 10-times Time:43ms
cutoff, 160000 10-times Time:42ms
cutoff, 170000 10-times Time:42ms
cutoff, 180000 10-times Time:42ms
cutoff, 190000 10-times Time:41ms
cutoff, 200000 10-times Time:41ms
cutoff, 210000 10-times Time:42ms
cutoff, 220000 10-times Time:41ms
cutoff, 230000 10-times Time:42ms
cutoff, 240000 10-times Time:41ms
Build completed successfully in 1 sec. 2 ms (moments ago) 539 CRLF UTF-8 4 spaces Spring2022
```

```
File Edit View Navigate Code Refactor Build Run Tools Git Window Help INFO6205 - Main.java
INFO6205 src main java edu neu coe info6205 sort par Main
Project
  Project
  INFO6205 C:\Users\prath\IdeaProjects\INFO6205
  idea
  src
Run: Main
  * This code has been fleshed out by Ziyao Qiao. Thanks very much.
  * TODO tidy it up a bit.
  14
  15
  16
  Run: Main
  cutoff, 490000 10-times Time:43ms
  cutoff, 500000 10-times Time:42ms
  Degree of parallelism: 4
  cutoff, 10000 10-times Time:26ms
  cutoff, 20000 10-times Time:25ms
  cutoff, 30000 10-times Time:28ms
  cutoff, 40000 10-times Time:26ms
  cutoff, 50000 10-times Time:32ms
  cutoff, 60000 10-times Time:32ms
  cutoff, 70000 10-times Time:32ms
  cutoff, 80000 10-times Time:32ms
  cutoff, 90000 10-times Time:43ms
  cutoff, 100000 10-times Time:41ms
  cutoff, 110000 10-times Time:42ms
  cutoff, 120000 10-times Time:39ms
  cutoff, 130000 10-times Time:40ms
  cutoff, 140000 10-times Time:40ms
  cutoff, 150000 10-times Time:41ms
  cutoff, 160000 10-times Time:40ms
  cutoff, 170000 10-times Time:41ms
  cutoff, 180000 10-times Time:41ms
  cutoff, 190000 10-times Time:42ms
  cutoff, 200000 10-times Time:41ms
  cutoff, 210000 10-times Time:43ms
  cutoff, 220000 10-times Time:41ms
  cutoff, 230000 10-times Time:40ms
  cutoff, 240000 10-times Time:40ms
  Build completed successfully in 1 sec. 2 ms (a minute ago)
  5:39 CRLF UTF-8 4 spaces Spring2022
```

```
File Edit View Navigate Code Refactor Build Run Tools Git Window Help INFO6205 - Main.java
INFO6205 src main java edu neu coe info6205 sort par Main
Project
  Project
  INFO6205 C:\Users\prath\IdeaProjects\INFO6205
  idea
  src
Run: Main
  * This code has been fleshed out by Ziyao Qiao. Thanks very much.
  * TODO tidy it up a bit.
  14
  15
  16
  Run: Main
  cutoff, 490000 10-times Time:40ms
  cutoff, 500000 10-times Time:40ms
  Degree of parallelism: 8
  cutoff, 10000 10-times Time:24ms
  cutoff, 20000 10-times Time:28ms
  cutoff, 30000 10-times Time:23ms
  cutoff, 40000 10-times Time:22ms
  cutoff, 50000 10-times Time:28ms
  cutoff, 60000 10-times Time:29ms
  cutoff, 70000 10-times Time:29ms
  cutoff, 80000 10-times Time:29ms
  cutoff, 90000 10-times Time:40ms
  cutoff, 100000 10-times Time:41ms
  cutoff, 110000 10-times Time:42ms
  cutoff, 120000 10-times Time:40ms
  cutoff, 130000 10-times Time:44ms
  cutoff, 140000 10-times Time:41ms
  cutoff, 150000 10-times Time:40ms
  cutoff, 160000 10-times Time:41ms
  cutoff, 170000 10-times Time:41ms
  cutoff, 180000 10-times Time:41ms
  cutoff, 190000 10-times Time:40ms
  cutoff, 200000 10-times Time:44ms
  cutoff, 210000 10-times Time:41ms
  cutoff, 220000 10-times Time:40ms
  cutoff, 230000 10-times Time:41ms
  cutoff, 240000 10-times Time:40ms
  Build completed successfully in 1 sec. 2 ms (2 minutes ago)
  5:39 CRLF UTF-8 4 spaces Spring2022
```

The screenshot shows the IntelliJ IDEA IDE with a project named 'INFO6205'. The 'Run' console displays the output of a Java program. The program iterates through cutoff values from 490,000 down to 240,000 in increments of 10,000. For each cutoff, it performs 10 times a task and reports the time taken. The 'Degree of parallelism' is set to 16. The output shows that as the cutoff value decreases, the time taken for each iteration also decreases. The build completed successfully in 1 sec, 2 ms (3 minutes ago).

```
INFO6205 [src \main \java \edu \neu \coe \info6205 \sort \par \Main]
Run: Main
cutoff: 490000 10-times Time:40ms
cutoff: 500000 10-times Time:43ms
Degree of parallelism: 16
cutoff: 10000 10-times Time:21ms
cutoff: 20000 10-times Time:22ms
cutoff: 30000 10-times Time:25ms
cutoff: 40000 10-times Time:22ms
cutoff: 50000 10-times Time:29ms
cutoff: 60000 10-times Time:29ms
cutoff: 70000 10-times Time:28ms
cutoff: 80000 10-times Time:29ms
cutoff: 90000 10-times Time:40ms
cutoff: 100000 10-times Time:41ms
cutoff: 110000 10-times Time:42ms
cutoff: 120000 10-times Time:48ms
cutoff: 130000 10-times Time:48ms
cutoff: 140000 10-times Time:48ms
cutoff: 150000 10-times Time:42ms
cutoff: 160000 10-times Time:39ms
cutoff: 170000 10-times Time:42ms
cutoff: 180000 10-times Time:41ms
cutoff: 190000 10-times Time:40ms
cutoff: 200000 10-times Time:40ms
cutoff: 210000 10-times Time:40ms
cutoff: 220000 10-times Time:41ms
cutoff: 230000 10-times Time:41ms
cutoff: 240000 10-times Time:42ms
```

The screenshot shows the IntelliJ IDEA IDE with the same project 'INFO6205'. The 'Run' console displays the output of the same Java program, but with the 'Degree of parallelism' set to 32. The program iterates through the same cutoff values from 490,000 down to 240,000. The output shows that the time taken for each iteration is generally lower compared to the first screenshot, reflecting the higher degree of parallelism. The build completed successfully in 1 sec, 2 ms (3 minutes ago).

```
INFO6205 [src \main \java \edu \neu \coe \info6205 \sort \par \Main]
Run: Main
cutoff: 490000 10-times Time:40ms
cutoff: 500000 10-times Time:48ms
Degree of parallelism: 32
cutoff: 10000 10-times Time:22ms
cutoff: 20000 10-times Time:21ms
cutoff: 30000 10-times Time:22ms
cutoff: 40000 10-times Time:24ms
cutoff: 50000 10-times Time:29ms
cutoff: 60000 10-times Time:29ms
cutoff: 70000 10-times Time:30ms
cutoff: 80000 10-times Time:31ms
cutoff: 90000 10-times Time:40ms
cutoff: 100000 10-times Time:41ms
cutoff: 110000 10-times Time:40ms
cutoff: 120000 10-times Time:41ms
cutoff: 130000 10-times Time:40ms
cutoff: 140000 10-times Time:41ms
cutoff: 150000 10-times Time:41ms
cutoff: 160000 10-times Time:48ms
cutoff: 170000 10-times Time:41ms
cutoff: 180000 10-times Time:41ms
cutoff: 190000 10-times Time:39ms
cutoff: 200000 10-times Time:48ms
cutoff: 210000 10-times Time:48ms
cutoff: 220000 10-times Time:40ms
cutoff: 230000 10-times Time:40ms
cutoff: 240000 10-times Time:41ms
```

The screenshot shows an IDE window titled "INFO6205 - Main.java". The code editor displays the following code:

```
14 * This code has been fleshed out by Ziyao Qiao. Thanks very much.  
15 * TODO tidy it up a bit.  
16 */
```

The Run console shows the output of the program:

```
Run: Main x  
cutoff, 490000 10-times Time:41ms  
cutoff, 500000 10-times Time:39ms  
Degree of parallelism: 64  
cutoff, 10000 10-times Time:23ms  
cutoff, 20000 10-times Time:21ms  
cutoff, 30000 10-times Time:23ms  
cutoff, 40000 10-times Time:23ms  
cutoff, 50000 10-times Time:28ms  
cutoff, 60000 10-times Time:31ms  
cutoff, 70000 10-times Time:29ms  
cutoff, 80000 10-times Time:28ms  
cutoff, 90000 10-times Time:40ms  
cutoff, 100000 10-times Time:41ms  
cutoff, 110000 10-times Time:39ms  
cutoff, 120000 10-times Time:41ms  
cutoff, 130000 10-times Time:40ms  
cutoff, 140000 10-times Time:41ms  
cutoff, 150000 10-times Time:40ms  
cutoff, 160000 10-times Time:40ms  
cutoff, 170000 10-times Time:40ms  
cutoff, 180000 10-times Time:41ms  
cutoff, 190000 10-times Time:39ms  
cutoff, 200000 10-times Time:41ms  
cutoff, 210000 10-times Time:40ms  
cutoff, 220000 10-times Time:40ms  
cutoff, 230000 10-times Time:41ms  
cutoff, 240000 10-times Time:41ms
```

The status bar at the bottom indicates: "Build completed successfully in 1 sec, 2 ms (3 minutes ago)" and "5:39 CRLF UTF-8 4 spaces Spring2022".