# INFO6205 Assignment 5 (Parallel Sorting)

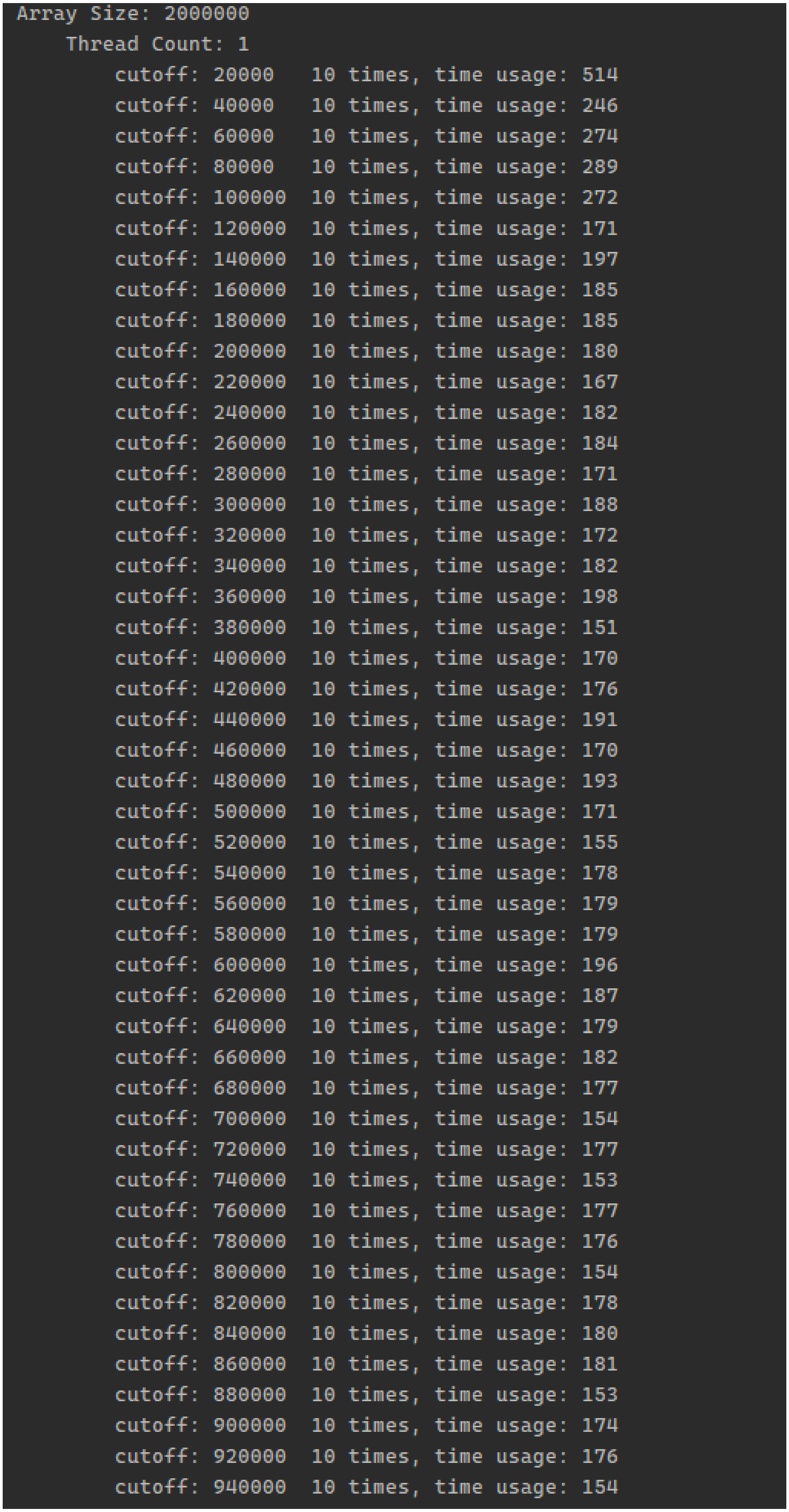
NAME: Bohan Feng

NUID: 001564249

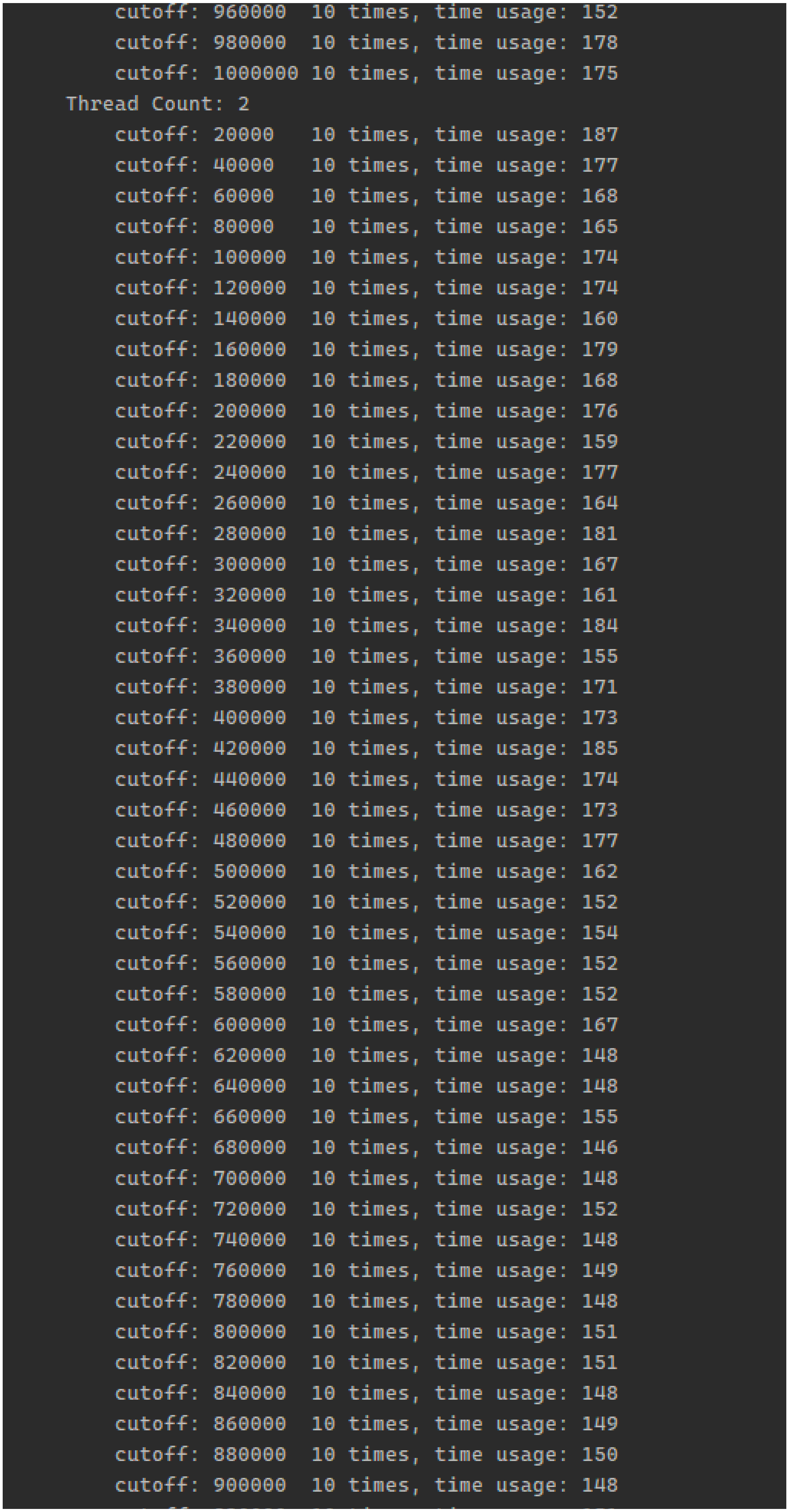
Repository: https://github.com/fengb3/INFO6205

## Output result

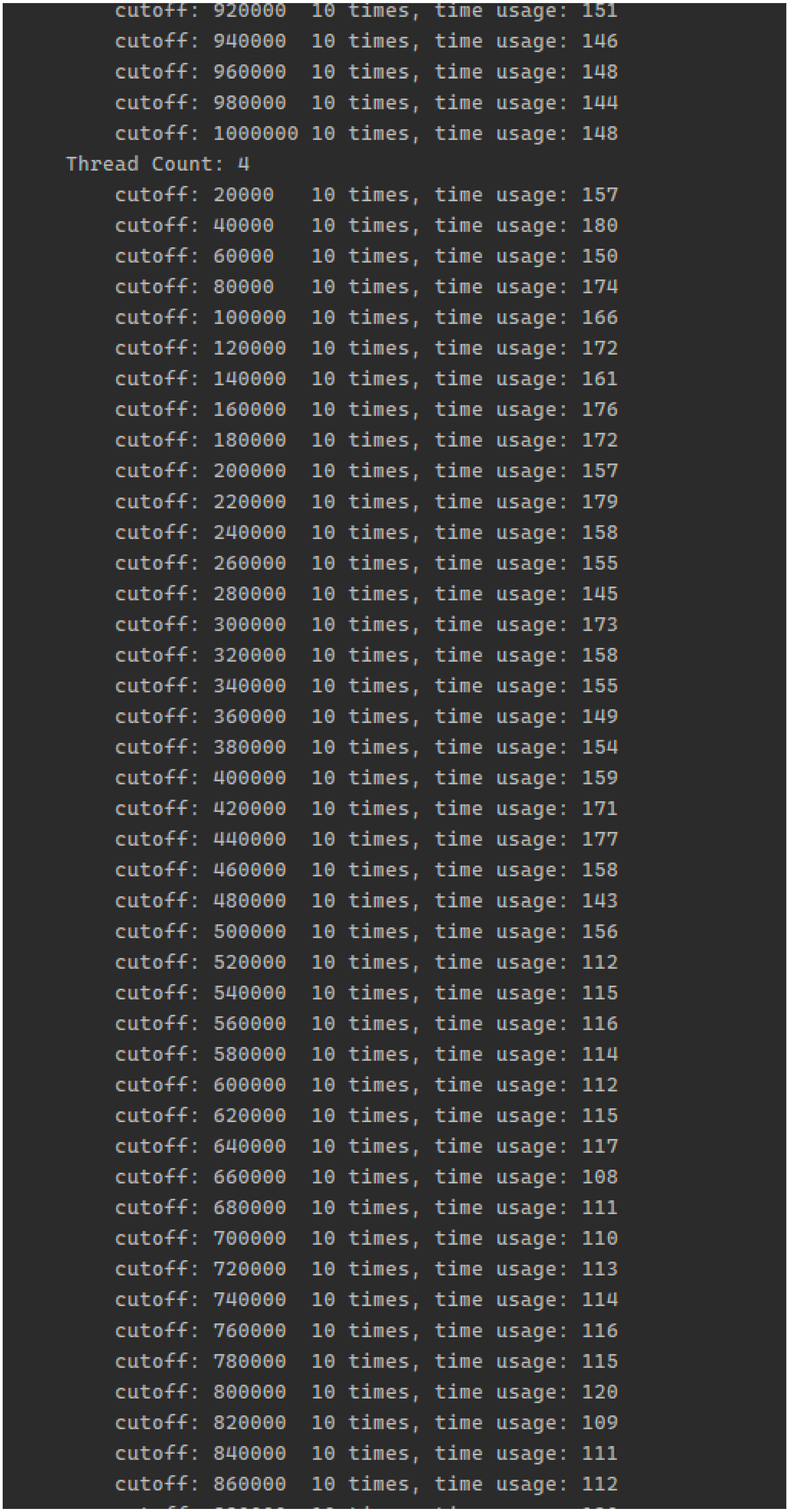
the console output looks like this



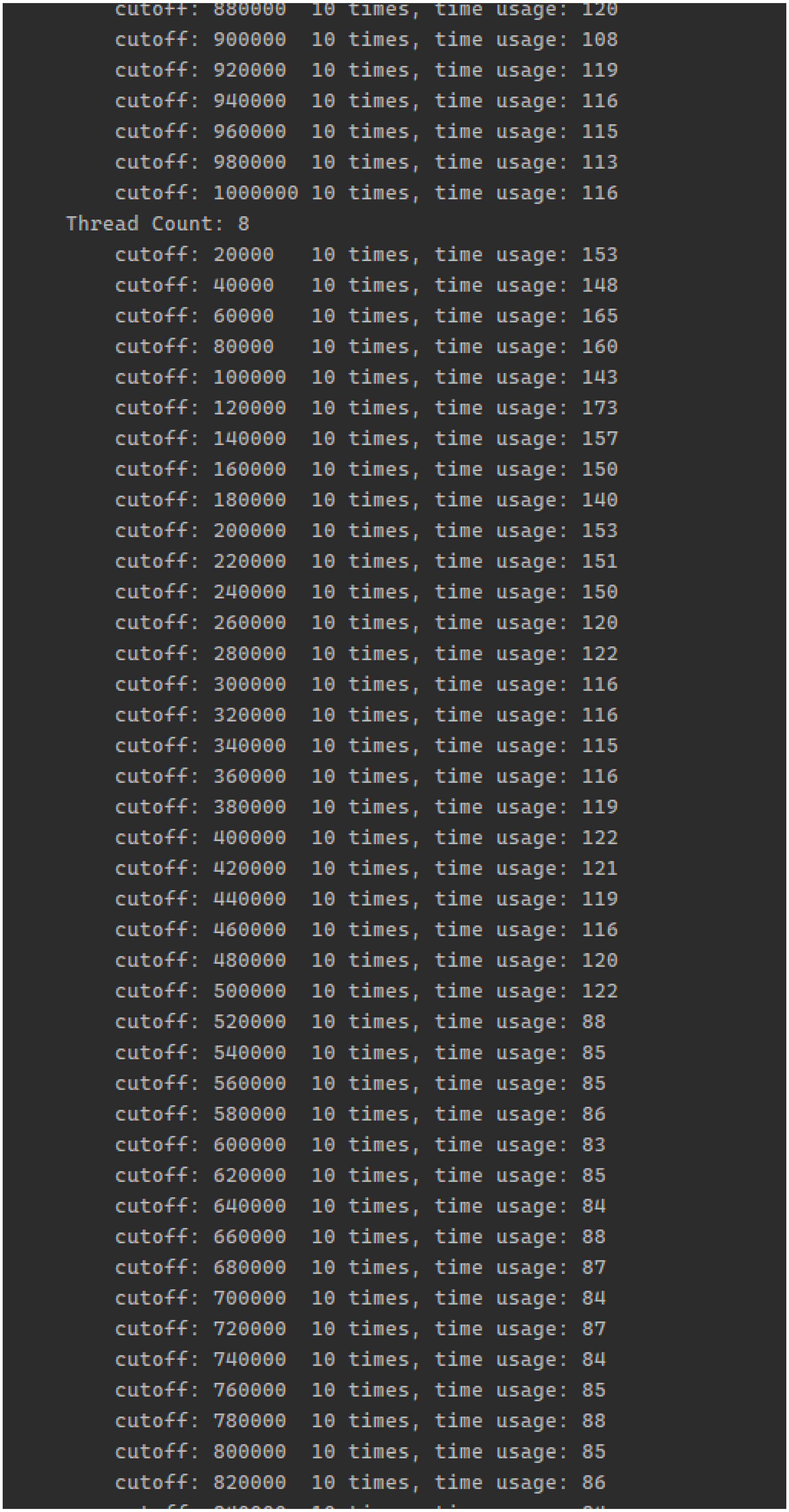
```
Array Size: 2000000
    Thread Count: 1
        cutoff: 20000   10 times, time usage: 514
        cutoff: 40000   10 times, time usage: 246
        cutoff: 60000   10 times, time usage: 274
        cutoff: 80000   10 times, time usage: 289
        cutoff: 100000  10 times, time usage: 272
        cutoff: 120000  10 times, time usage: 171
        cutoff: 140000  10 times, time usage: 197
        cutoff: 160000  10 times, time usage: 185
        cutoff: 180000  10 times, time usage: 185
        cutoff: 200000  10 times, time usage: 180
        cutoff: 220000  10 times, time usage: 167
        cutoff: 240000  10 times, time usage: 182
        cutoff: 260000  10 times, time usage: 184
        cutoff: 280000  10 times, time usage: 171
        cutoff: 300000  10 times, time usage: 188
        cutoff: 320000  10 times, time usage: 172
        cutoff: 340000  10 times, time usage: 182
        cutoff: 360000  10 times, time usage: 198
        cutoff: 380000  10 times, time usage: 151
        cutoff: 400000  10 times, time usage: 170
        cutoff: 420000  10 times, time usage: 176
        cutoff: 440000  10 times, time usage: 191
        cutoff: 460000  10 times, time usage: 170
        cutoff: 480000  10 times, time usage: 193
        cutoff: 500000  10 times, time usage: 171
        cutoff: 520000  10 times, time usage: 155
        cutoff: 540000  10 times, time usage: 178
        cutoff: 560000  10 times, time usage: 179
        cutoff: 580000  10 times, time usage: 179
        cutoff: 600000  10 times, time usage: 196
        cutoff: 620000  10 times, time usage: 187
        cutoff: 640000  10 times, time usage: 179
        cutoff: 660000  10 times, time usage: 182
        cutoff: 680000  10 times, time usage: 177
        cutoff: 700000  10 times, time usage: 154
        cutoff: 720000  10 times, time usage: 177
        cutoff: 740000  10 times, time usage: 153
        cutoff: 760000  10 times, time usage: 177
        cutoff: 780000  10 times, time usage: 176
        cutoff: 800000  10 times, time usage: 154
        cutoff: 820000  10 times, time usage: 178
        cutoff: 840000  10 times, time usage: 180
        cutoff: 860000  10 times, time usage: 181
        cutoff: 880000  10 times, time usage: 153
        cutoff: 900000  10 times, time usage: 174
        cutoff: 920000  10 times, time usage: 176
        cutoff: 940000  10 times, time usage: 154
```



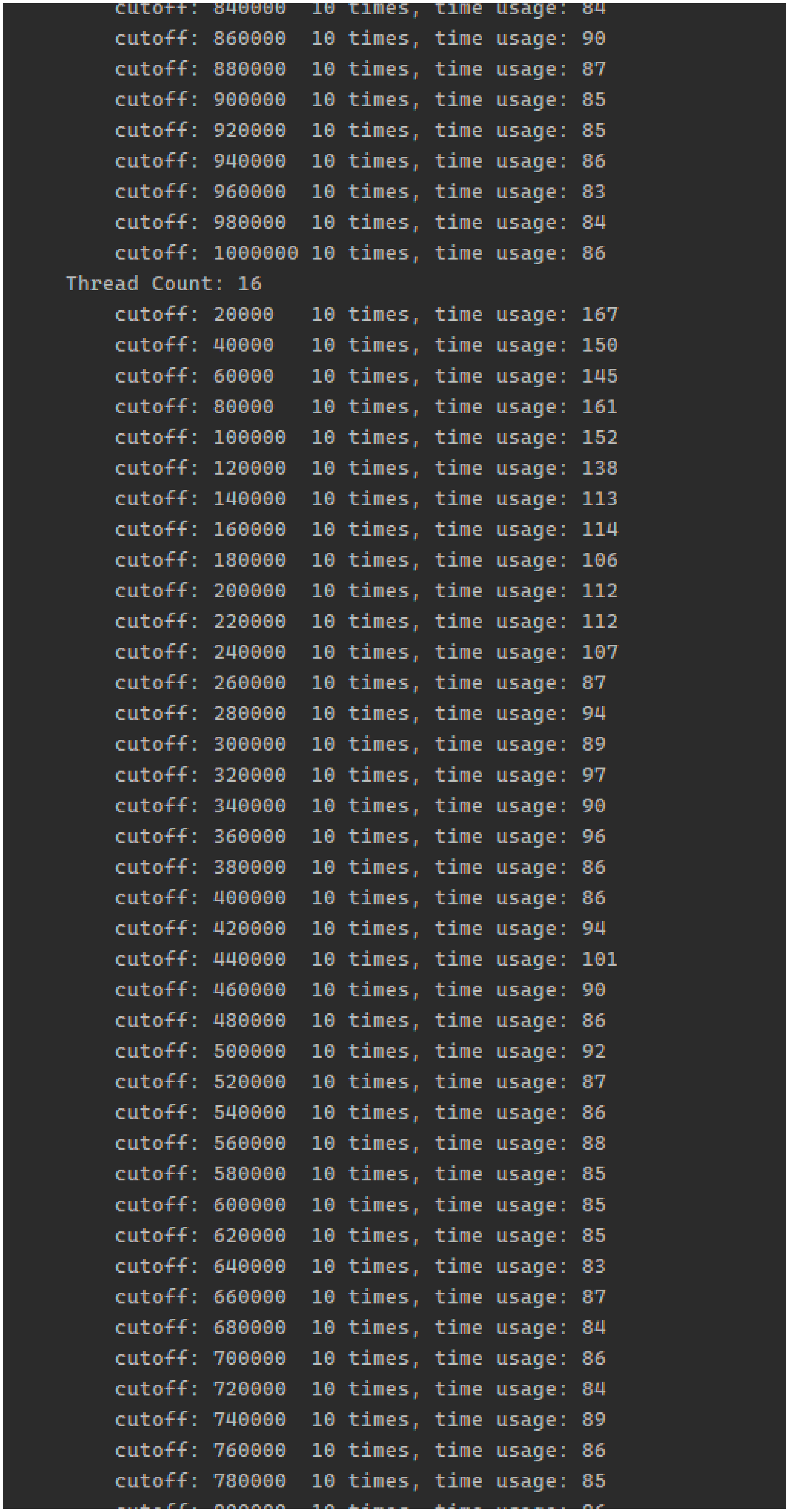
```
        cutoff: 960000  10 times, time usage: 152
        cutoff: 980000  10 times, time usage: 178
        cutoff: 1000000 10 times, time usage: 175
    Thread Count: 2
        cutoff: 20000   10 times, time usage: 187
        cutoff: 40000   10 times, time usage: 177
        cutoff: 60000   10 times, time usage: 168
        cutoff: 80000   10 times, time usage: 165
        cutoff: 100000  10 times, time usage: 174
        cutoff: 120000  10 times, time usage: 174
        cutoff: 140000  10 times, time usage: 160
        cutoff: 160000  10 times, time usage: 179
        cutoff: 180000  10 times, time usage: 168
        cutoff: 200000  10 times, time usage: 176
        cutoff: 220000  10 times, time usage: 159
        cutoff: 240000  10 times, time usage: 177
        cutoff: 260000  10 times, time usage: 164
        cutoff: 280000  10 times, time usage: 181
        cutoff: 300000  10 times, time usage: 167
        cutoff: 320000  10 times, time usage: 161
        cutoff: 340000  10 times, time usage: 184
        cutoff: 360000  10 times, time usage: 155
        cutoff: 380000  10 times, time usage: 171
        cutoff: 400000  10 times, time usage: 173
        cutoff: 420000  10 times, time usage: 185
        cutoff: 440000  10 times, time usage: 174
        cutoff: 460000  10 times, time usage: 173
        cutoff: 480000  10 times, time usage: 177
        cutoff: 500000  10 times, time usage: 162
        cutoff: 520000  10 times, time usage: 152
        cutoff: 540000  10 times, time usage: 154
        cutoff: 560000  10 times, time usage: 152
        cutoff: 580000  10 times, time usage: 152
        cutoff: 600000  10 times, time usage: 167
        cutoff: 620000  10 times, time usage: 148
        cutoff: 640000  10 times, time usage: 148
        cutoff: 660000  10 times, time usage: 155
        cutoff: 680000  10 times, time usage: 146
        cutoff: 700000  10 times, time usage: 148
        cutoff: 720000  10 times, time usage: 152
        cutoff: 740000  10 times, time usage: 148
        cutoff: 760000  10 times, time usage: 149
        cutoff: 780000  10 times, time usage: 148
        cutoff: 800000  10 times, time usage: 151
        cutoff: 820000  10 times, time usage: 151
        cutoff: 840000  10 times, time usage: 148
        cutoff: 860000  10 times, time usage: 149
        cutoff: 880000  10 times, time usage: 150
        cutoff: 900000  10 times, time usage: 148
```



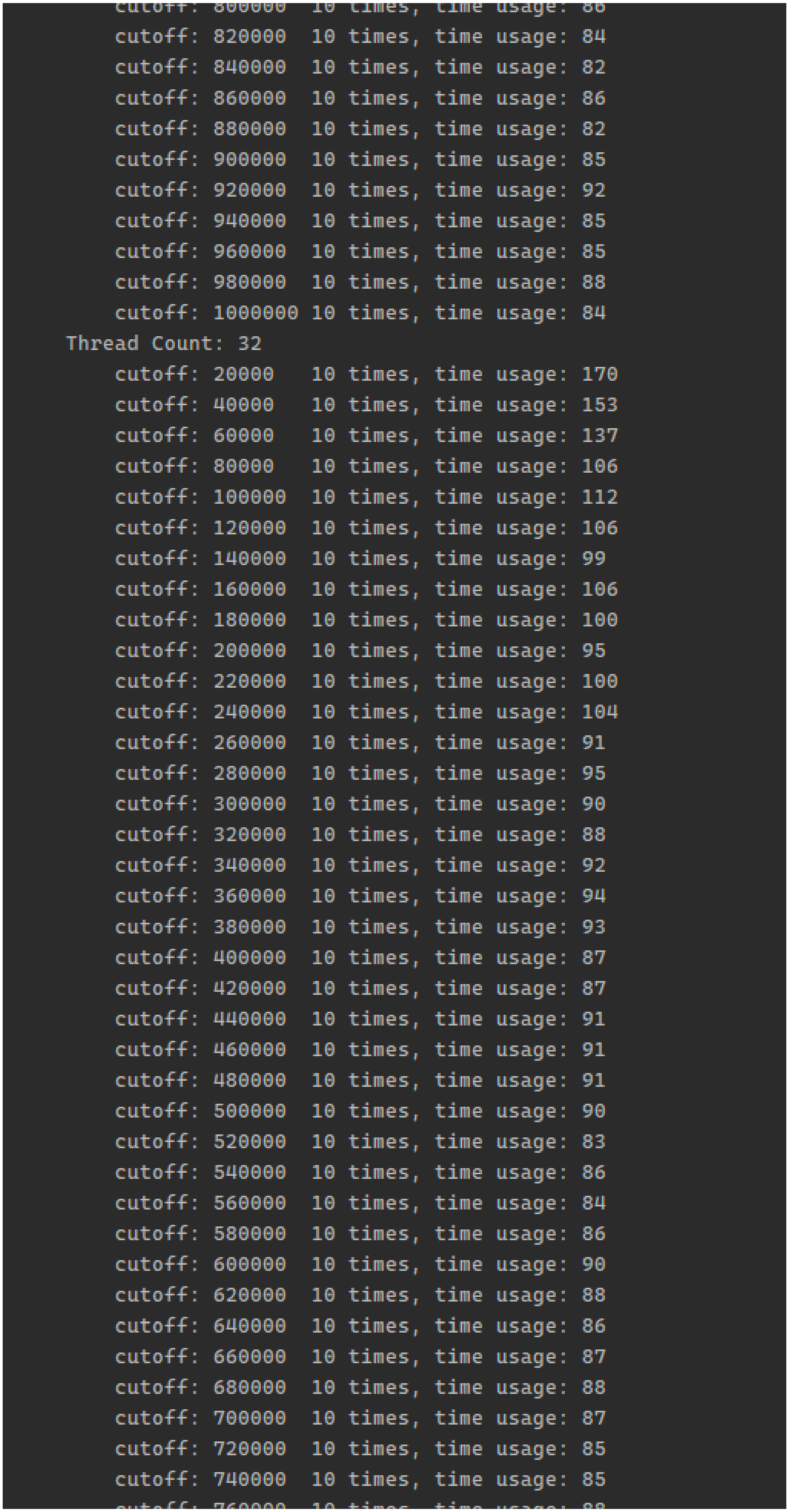
```
        cutoff: 920000  10 times, time usage: 151
        cutoff: 940000  10 times, time usage: 146
        cutoff: 960000  10 times, time usage: 148
        cutoff: 980000  10 times, time usage: 144
        cutoff: 1000000 10 times, time usage: 148
    Thread Count: 4
        cutoff: 20000   10 times, time usage: 157
        cutoff: 40000   10 times, time usage: 180
        cutoff: 60000   10 times, time usage: 150
        cutoff: 80000   10 times, time usage: 174
        cutoff: 100000  10 times, time usage: 166
        cutoff: 120000  10 times, time usage: 172
        cutoff: 140000  10 times, time usage: 161
        cutoff: 160000  10 times, time usage: 176
        cutoff: 180000  10 times, time usage: 172
        cutoff: 200000  10 times, time usage: 157
        cutoff: 220000  10 times, time usage: 179
        cutoff: 240000  10 times, time usage: 158
        cutoff: 260000  10 times, time usage: 155
        cutoff: 280000  10 times, time usage: 145
        cutoff: 300000  10 times, time usage: 173
        cutoff: 320000  10 times, time usage: 158
        cutoff: 340000  10 times, time usage: 155
        cutoff: 360000  10 times, time usage: 149
        cutoff: 380000  10 times, time usage: 154
        cutoff: 400000  10 times, time usage: 159
        cutoff: 420000  10 times, time usage: 171
        cutoff: 440000  10 times, time usage: 177
        cutoff: 460000  10 times, time usage: 158
        cutoff: 480000  10 times, time usage: 143
        cutoff: 500000  10 times, time usage: 156
        cutoff: 520000  10 times, time usage: 112
        cutoff: 540000  10 times, time usage: 115
        cutoff: 560000  10 times, time usage: 116
        cutoff: 580000  10 times, time usage: 114
        cutoff: 600000  10 times, time usage: 112
        cutoff: 620000  10 times, time usage: 115
        cutoff: 640000  10 times, time usage: 117
        cutoff: 660000  10 times, time usage: 108
        cutoff: 680000  10 times, time usage: 111
        cutoff: 700000  10 times, time usage: 110
        cutoff: 720000  10 times, time usage: 113
        cutoff: 740000  10 times, time usage: 114
        cutoff: 760000  10 times, time usage: 116
        cutoff: 780000  10 times, time usage: 115
        cutoff: 800000  10 times, time usage: 120
        cutoff: 820000  10 times, time usage: 109
        cutoff: 840000  10 times, time usage: 111
        cutoff: 860000  10 times, time usage: 112
```



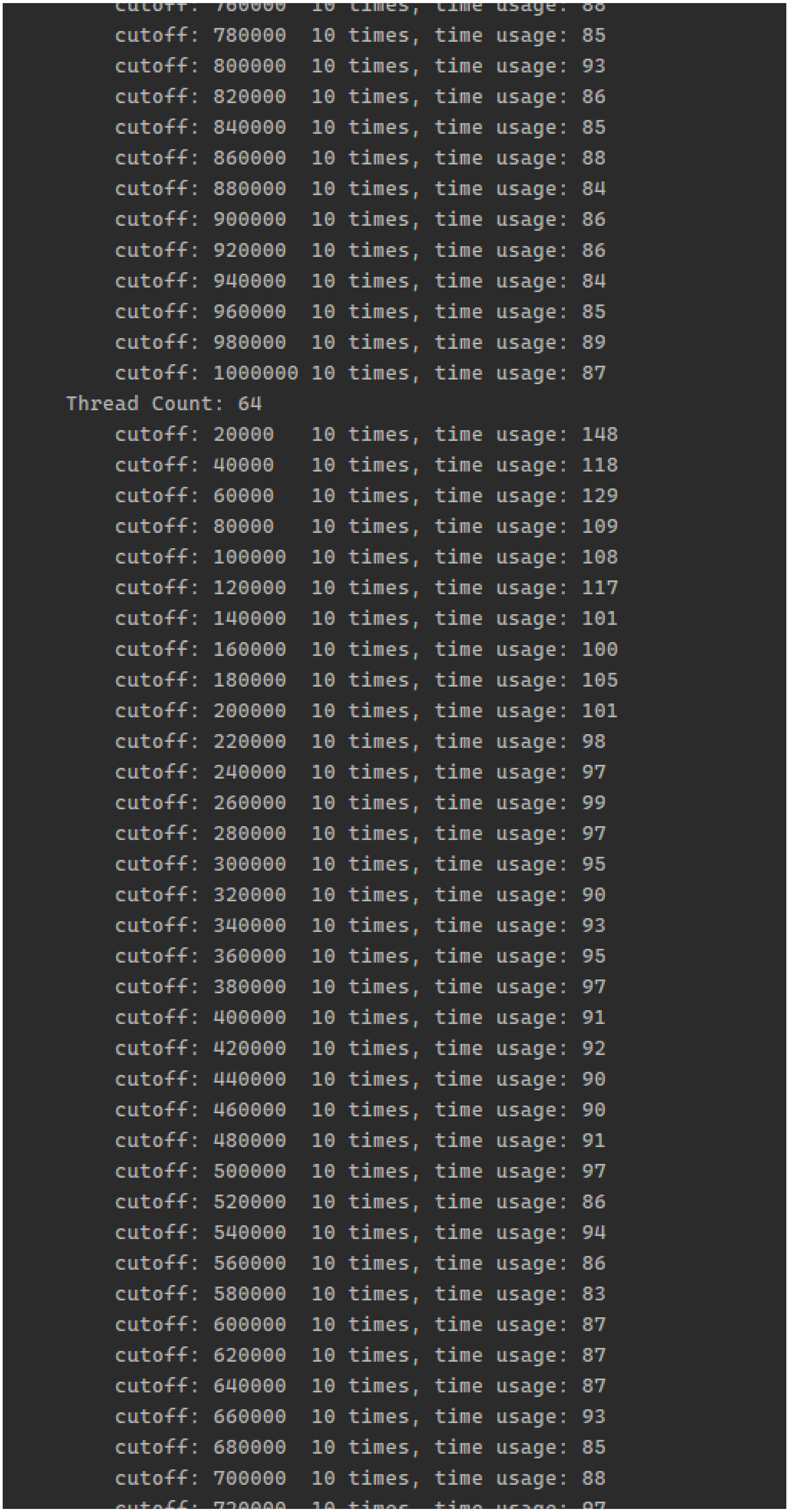
```
    cutoff: 880000  10 times, time usage: 120
    cutoff: 900000  10 times, time usage: 108
    cutoff: 920000  10 times, time usage: 119
    cutoff: 940000  10 times, time usage: 116
    cutoff: 960000  10 times, time usage: 115
    cutoff: 980000  10 times, time usage: 113
    cutoff: 1000000 10 times, time usage: 116
Thread Count: 8
    cutoff: 20000   10 times, time usage: 153
    cutoff: 40000   10 times, time usage: 148
    cutoff: 60000   10 times, time usage: 165
    cutoff: 80000   10 times, time usage: 160
    cutoff: 100000  10 times, time usage: 143
    cutoff: 120000  10 times, time usage: 173
    cutoff: 140000  10 times, time usage: 157
    cutoff: 160000  10 times, time usage: 150
    cutoff: 180000  10 times, time usage: 140
    cutoff: 200000  10 times, time usage: 153
    cutoff: 220000  10 times, time usage: 151
    cutoff: 240000  10 times, time usage: 150
    cutoff: 260000  10 times, time usage: 120
    cutoff: 280000  10 times, time usage: 122
    cutoff: 300000  10 times, time usage: 116
    cutoff: 320000  10 times, time usage: 116
    cutoff: 340000  10 times, time usage: 115
    cutoff: 360000  10 times, time usage: 116
    cutoff: 380000  10 times, time usage: 119
    cutoff: 400000  10 times, time usage: 122
    cutoff: 420000  10 times, time usage: 121
    cutoff: 440000  10 times, time usage: 119
    cutoff: 460000  10 times, time usage: 116
    cutoff: 480000  10 times, time usage: 120
    cutoff: 500000  10 times, time usage: 122
    cutoff: 520000  10 times, time usage: 88
    cutoff: 540000  10 times, time usage: 85
    cutoff: 560000  10 times, time usage: 85
    cutoff: 580000  10 times, time usage: 86
    cutoff: 600000  10 times, time usage: 83
    cutoff: 620000  10 times, time usage: 85
    cutoff: 640000  10 times, time usage: 84
    cutoff: 660000  10 times, time usage: 88
    cutoff: 680000  10 times, time usage: 87
    cutoff: 700000  10 times, time usage: 84
    cutoff: 720000  10 times, time usage: 87
    cutoff: 740000  10 times, time usage: 84
    cutoff: 760000  10 times, time usage: 85
    cutoff: 780000  10 times, time usage: 88
    cutoff: 800000  10 times, time usage: 85
    cutoff: 820000  10 times, time usage: 86
    cutoff: 840000  10 times, time usage: 84
```



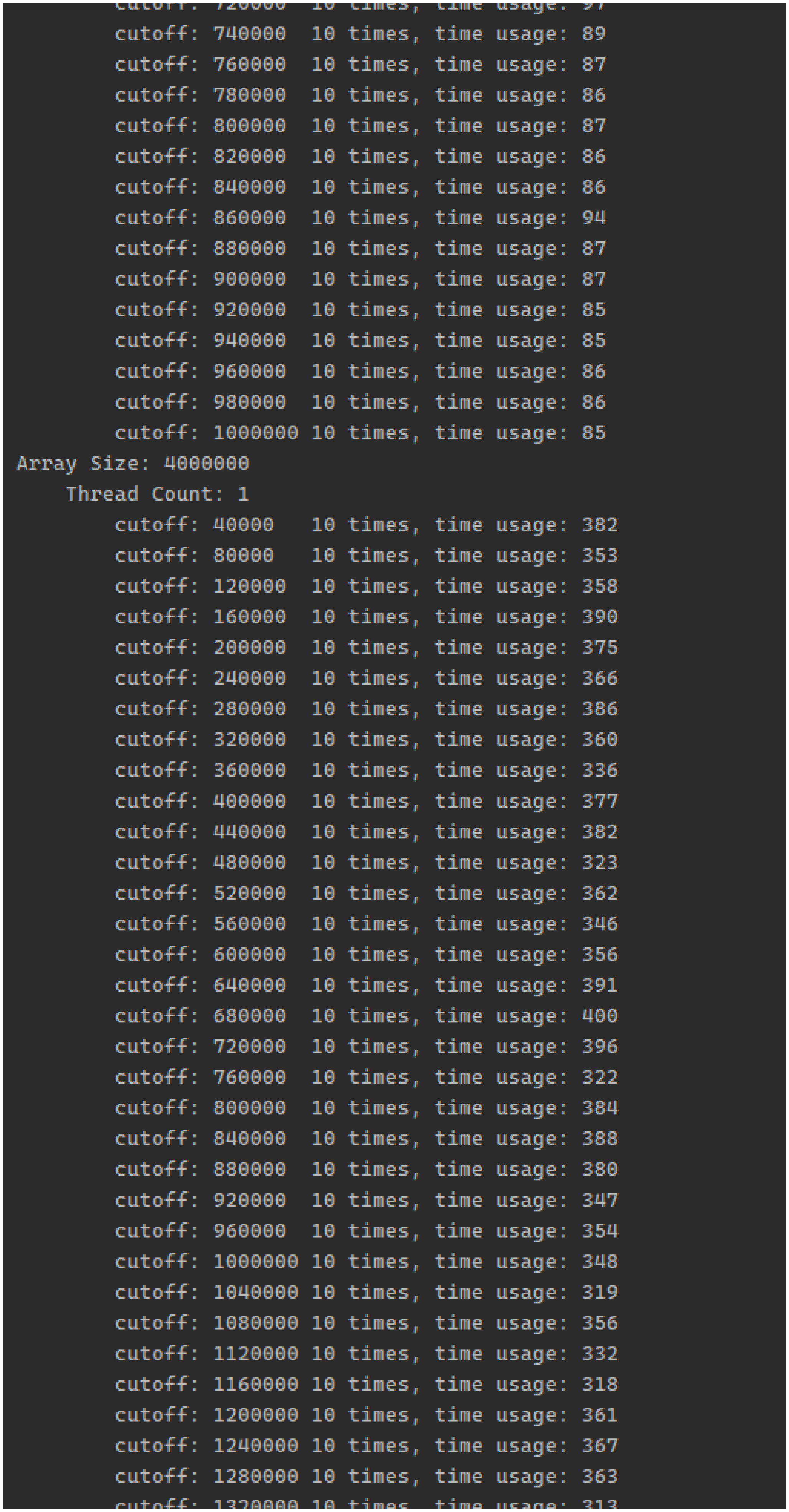
```
    cutoff: 840000  10 times, time usage: 84
    cutoff: 860000  10 times, time usage: 90
    cutoff: 880000  10 times, time usage: 87
    cutoff: 900000  10 times, time usage: 85
    cutoff: 920000  10 times, time usage: 85
    cutoff: 940000  10 times, time usage: 86
    cutoff: 960000  10 times, time usage: 83
    cutoff: 980000  10 times, time usage: 84
    cutoff: 1000000 10 times, time usage: 86
Thread Count: 16
    cutoff: 20000   10 times, time usage: 167
    cutoff: 40000   10 times, time usage: 150
    cutoff: 60000   10 times, time usage: 145
    cutoff: 80000   10 times, time usage: 161
    cutoff: 100000  10 times, time usage: 152
    cutoff: 120000  10 times, time usage: 138
    cutoff: 140000  10 times, time usage: 113
    cutoff: 160000  10 times, time usage: 114
    cutoff: 180000  10 times, time usage: 106
    cutoff: 200000  10 times, time usage: 112
    cutoff: 220000  10 times, time usage: 112
    cutoff: 240000  10 times, time usage: 107
    cutoff: 260000  10 times, time usage: 87
    cutoff: 280000  10 times, time usage: 94
    cutoff: 300000  10 times, time usage: 89
    cutoff: 320000  10 times, time usage: 97
    cutoff: 340000  10 times, time usage: 90
    cutoff: 360000  10 times, time usage: 96
    cutoff: 380000  10 times, time usage: 86
    cutoff: 400000  10 times, time usage: 86
    cutoff: 420000  10 times, time usage: 94
    cutoff: 440000  10 times, time usage: 101
    cutoff: 460000  10 times, time usage: 90
    cutoff: 480000  10 times, time usage: 86
    cutoff: 500000  10 times, time usage: 92
    cutoff: 520000  10 times, time usage: 87
    cutoff: 540000  10 times, time usage: 86
    cutoff: 560000  10 times, time usage: 88
    cutoff: 580000  10 times, time usage: 85
    cutoff: 600000  10 times, time usage: 85
    cutoff: 620000  10 times, time usage: 85
    cutoff: 640000  10 times, time usage: 83
    cutoff: 660000  10 times, time usage: 87
    cutoff: 680000  10 times, time usage: 84
    cutoff: 700000  10 times, time usage: 86
    cutoff: 720000  10 times, time usage: 84
    cutoff: 740000  10 times, time usage: 89
    cutoff: 760000  10 times, time usage: 86
    cutoff: 780000  10 times, time usage: 85
    cutoff: 800000  10 times, time usage: 86
```



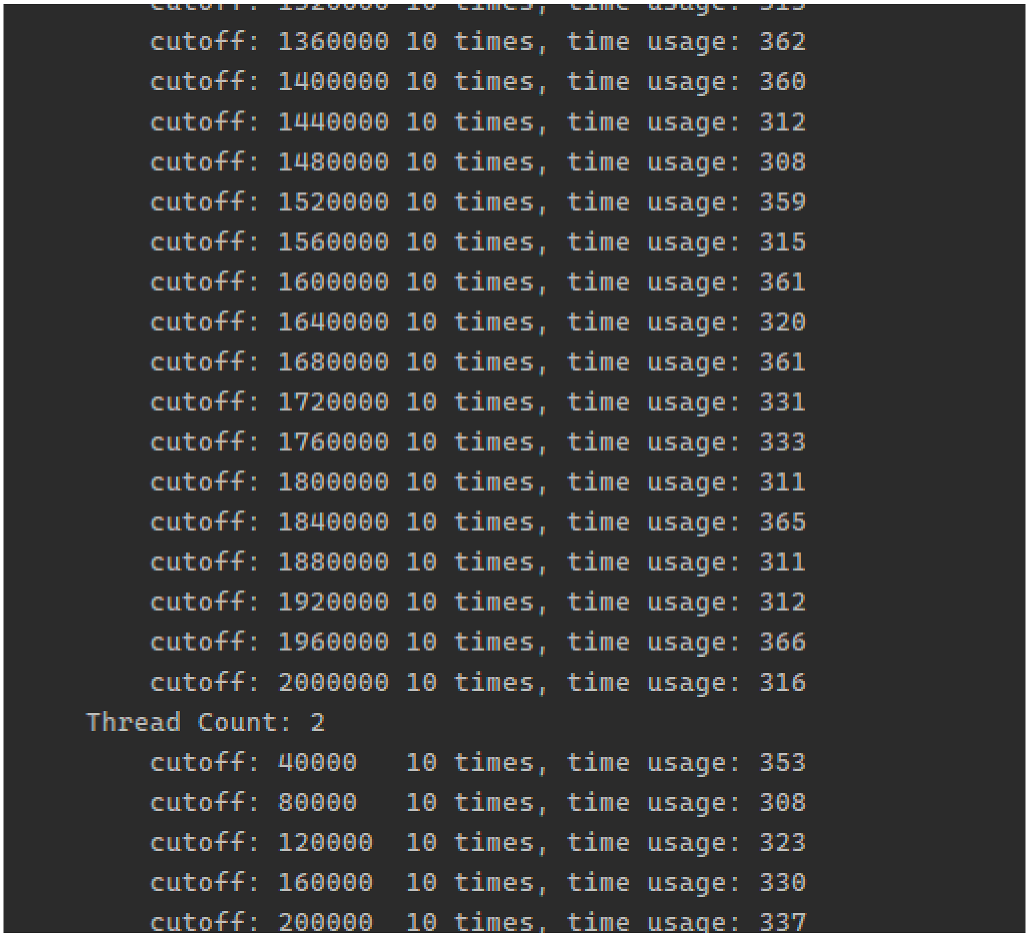
```
        cutoff: 800000  10 times, time usage: 86
        cutoff: 820000  10 times, time usage: 84
        cutoff: 840000  10 times, time usage: 82
        cutoff: 860000  10 times, time usage: 86
        cutoff: 880000  10 times, time usage: 82
        cutoff: 900000  10 times, time usage: 85
        cutoff: 920000  10 times, time usage: 92
        cutoff: 940000  10 times, time usage: 85
        cutoff: 960000  10 times, time usage: 85
        cutoff: 980000  10 times, time usage: 88
        cutoff: 1000000 10 times, time usage: 84
    Thread Count: 32
        cutoff: 20000   10 times, time usage: 170
        cutoff: 40000   10 times, time usage: 153
        cutoff: 60000   10 times, time usage: 137
        cutoff: 80000   10 times, time usage: 106
        cutoff: 100000  10 times, time usage: 112
        cutoff: 120000  10 times, time usage: 106
        cutoff: 140000  10 times, time usage: 99
        cutoff: 160000  10 times, time usage: 106
        cutoff: 180000  10 times, time usage: 100
        cutoff: 200000  10 times, time usage: 95
        cutoff: 220000  10 times, time usage: 100
        cutoff: 240000  10 times, time usage: 104
        cutoff: 260000  10 times, time usage: 91
        cutoff: 280000  10 times, time usage: 95
        cutoff: 300000  10 times, time usage: 90
        cutoff: 320000  10 times, time usage: 88
        cutoff: 340000  10 times, time usage: 92
        cutoff: 360000  10 times, time usage: 94
        cutoff: 380000  10 times, time usage: 93
        cutoff: 400000  10 times, time usage: 87
        cutoff: 420000  10 times, time usage: 87
        cutoff: 440000  10 times, time usage: 91
        cutoff: 460000  10 times, time usage: 91
        cutoff: 480000  10 times, time usage: 91
        cutoff: 500000  10 times, time usage: 90
        cutoff: 520000  10 times, time usage: 83
        cutoff: 540000  10 times, time usage: 86
        cutoff: 560000  10 times, time usage: 84
        cutoff: 580000  10 times, time usage: 86
        cutoff: 600000  10 times, time usage: 90
        cutoff: 620000  10 times, time usage: 88
        cutoff: 640000  10 times, time usage: 86
        cutoff: 660000  10 times, time usage: 87
        cutoff: 680000  10 times, time usage: 88
        cutoff: 700000  10 times, time usage: 87
        cutoff: 720000  10 times, time usage: 85
        cutoff: 740000  10 times, time usage: 85
        cutoff: 760000  10 times, time usage: 88
```



```
        cutoff: 760000  10 times, time usage: 88
        cutoff: 780000  10 times, time usage: 85
        cutoff: 800000  10 times, time usage: 93
        cutoff: 820000  10 times, time usage: 86
        cutoff: 840000  10 times, time usage: 85
        cutoff: 860000  10 times, time usage: 88
        cutoff: 880000  10 times, time usage: 84
        cutoff: 900000  10 times, time usage: 86
        cutoff: 920000  10 times, time usage: 86
        cutoff: 940000  10 times, time usage: 84
        cutoff: 960000  10 times, time usage: 85
        cutoff: 980000  10 times, time usage: 89
        cutoff: 1000000 10 times, time usage: 87
    Thread Count: 64
        cutoff: 20000   10 times, time usage: 148
        cutoff: 40000   10 times, time usage: 118
        cutoff: 60000   10 times, time usage: 129
        cutoff: 80000   10 times, time usage: 109
        cutoff: 100000  10 times, time usage: 108
        cutoff: 120000  10 times, time usage: 117
        cutoff: 140000  10 times, time usage: 101
        cutoff: 160000  10 times, time usage: 100
        cutoff: 180000  10 times, time usage: 105
        cutoff: 200000  10 times, time usage: 101
        cutoff: 220000  10 times, time usage: 98
        cutoff: 240000  10 times, time usage: 97
        cutoff: 260000  10 times, time usage: 99
        cutoff: 280000  10 times, time usage: 97
        cutoff: 300000  10 times, time usage: 95
        cutoff: 320000  10 times, time usage: 90
        cutoff: 340000  10 times, time usage: 93
        cutoff: 360000  10 times, time usage: 95
        cutoff: 380000  10 times, time usage: 97
        cutoff: 400000  10 times, time usage: 91
        cutoff: 420000  10 times, time usage: 92
        cutoff: 440000  10 times, time usage: 90
        cutoff: 460000  10 times, time usage: 90
        cutoff: 480000  10 times, time usage: 91
        cutoff: 500000  10 times, time usage: 97
        cutoff: 520000  10 times, time usage: 86
        cutoff: 540000  10 times, time usage: 94
        cutoff: 560000  10 times, time usage: 86
        cutoff: 580000  10 times, time usage: 83
        cutoff: 600000  10 times, time usage: 87
        cutoff: 620000  10 times, time usage: 87
        cutoff: 640000  10 times, time usage: 87
        cutoff: 660000  10 times, time usage: 93
        cutoff: 680000  10 times, time usage: 85
        cutoff: 700000  10 times, time usage: 88
        cutoff: 720000  10 times, time usage: 97
```



```
        cutoff: 720000  10 times, time usage: 97
        cutoff: 740000  10 times, time usage: 89
        cutoff: 760000  10 times, time usage: 87
        cutoff: 780000  10 times, time usage: 86
        cutoff: 800000  10 times, time usage: 87
        cutoff: 820000  10 times, time usage: 86
        cutoff: 840000  10 times, time usage: 86
        cutoff: 860000  10 times, time usage: 94
        cutoff: 880000  10 times, time usage: 87
        cutoff: 900000  10 times, time usage: 87
        cutoff: 920000  10 times, time usage: 85
        cutoff: 940000  10 times, time usage: 85
        cutoff: 960000  10 times, time usage: 86
        cutoff: 980000  10 times, time usage: 86
        cutoff: 1000000 10 times, time usage: 85
Array Size: 4000000
    Thread Count: 1
        cutoff: 40000   10 times, time usage: 382
        cutoff: 80000   10 times, time usage: 353
        cutoff: 120000  10 times, time usage: 358
        cutoff: 160000  10 times, time usage: 390
        cutoff: 200000  10 times, time usage: 375
        cutoff: 240000  10 times, time usage: 366
        cutoff: 280000  10 times, time usage: 386
        cutoff: 320000  10 times, time usage: 360
        cutoff: 360000  10 times, time usage: 336
        cutoff: 400000  10 times, time usage: 377
        cutoff: 440000  10 times, time usage: 382
        cutoff: 480000  10 times, time usage: 323
        cutoff: 520000  10 times, time usage: 362
        cutoff: 560000  10 times, time usage: 346
        cutoff: 600000  10 times, time usage: 356
        cutoff: 640000  10 times, time usage: 391
        cutoff: 680000  10 times, time usage: 400
        cutoff: 720000  10 times, time usage: 396
        cutoff: 760000  10 times, time usage: 322
        cutoff: 800000  10 times, time usage: 384
        cutoff: 840000  10 times, time usage: 388
        cutoff: 880000  10 times, time usage: 380
        cutoff: 920000  10 times, time usage: 347
        cutoff: 960000  10 times, time usage: 354
        cutoff: 1000000 10 times, time usage: 348
        cutoff: 1040000 10 times, time usage: 319
        cutoff: 1080000 10 times, time usage: 356
        cutoff: 1120000 10 times, time usage: 332
        cutoff: 1160000 10 times, time usage: 318
        cutoff: 1200000 10 times, time usage: 361
        cutoff: 1240000 10 times, time usage: 367
        cutoff: 1280000 10 times, time usage: 363
        cutoff: 1320000 10 times, time usage: 313
```

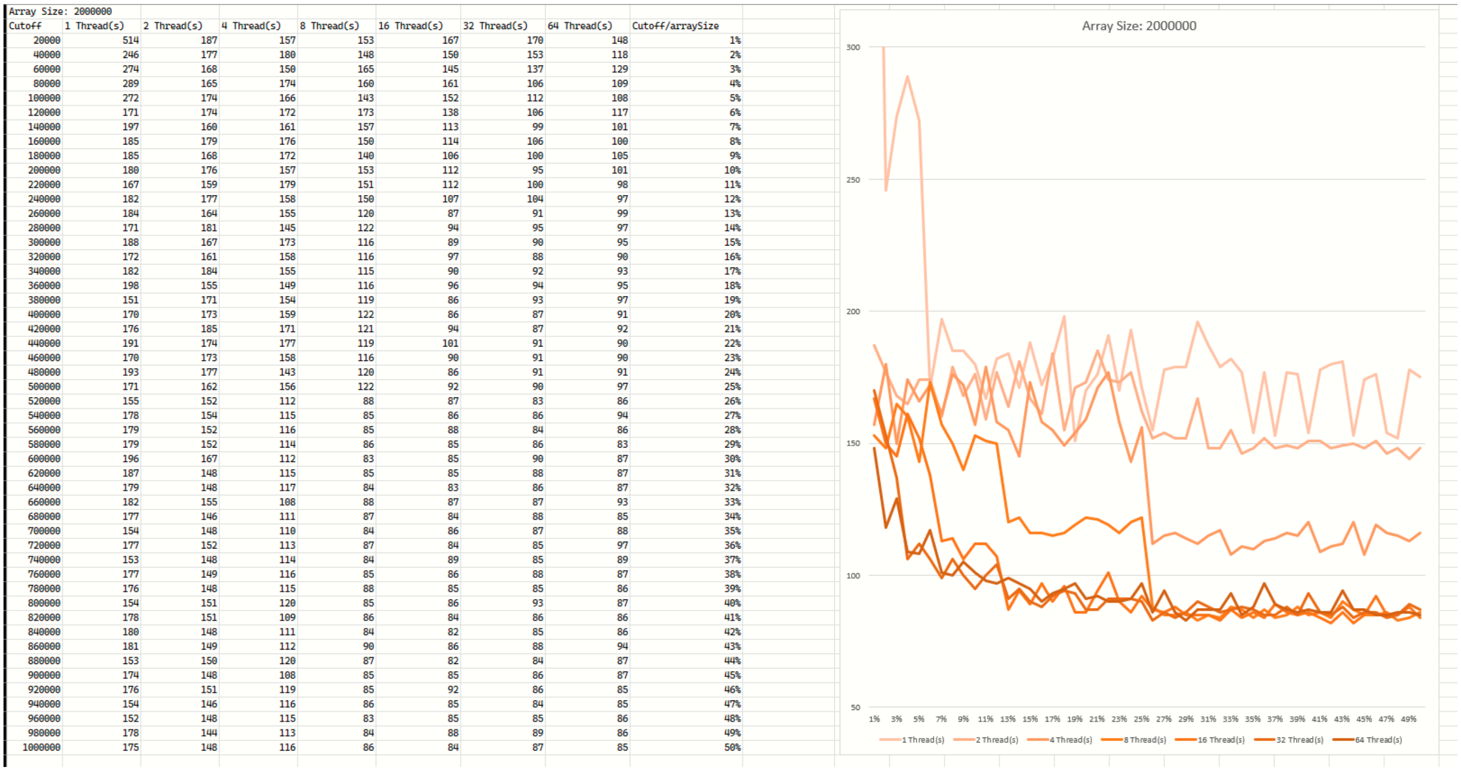


```
        cutoff: 1320000 10 times, time usage: 313
        cutoff: 1360000 10 times, time usage: 362
        cutoff: 1400000 10 times, time usage: 360
        cutoff: 1440000 10 times, time usage: 312
        cutoff: 1480000 10 times, time usage: 308
        cutoff: 1520000 10 times, time usage: 359
        cutoff: 1560000 10 times, time usage: 315
        cutoff: 1600000 10 times, time usage: 361
        cutoff: 1640000 10 times, time usage: 320
        cutoff: 1680000 10 times, time usage: 361
        cutoff: 1720000 10 times, time usage: 331
        cutoff: 1760000 10 times, time usage: 333
        cutoff: 1800000 10 times, time usage: 311
        cutoff: 1840000 10 times, time usage: 365
        cutoff: 1880000 10 times, time usage: 311
        cutoff: 1920000 10 times, time usage: 312
        cutoff: 1960000 10 times, time usage: 366
        cutoff: 2000000 10 times, time usage: 316
    Thread Count: 2
        cutoff: 40000   10 times, time usage: 353
        cutoff: 80000   10 times, time usage: 308
        cutoff: 120000  10 times, time usage: 323
        cutoff: 160000  10 times, time usage: 330
        cutoff: 200000  10 times, time usage: 337
```

# Graph

I try 5 different value for size of array (2 million to 10 million). The cutoff value increasing based on the percentage of array size.

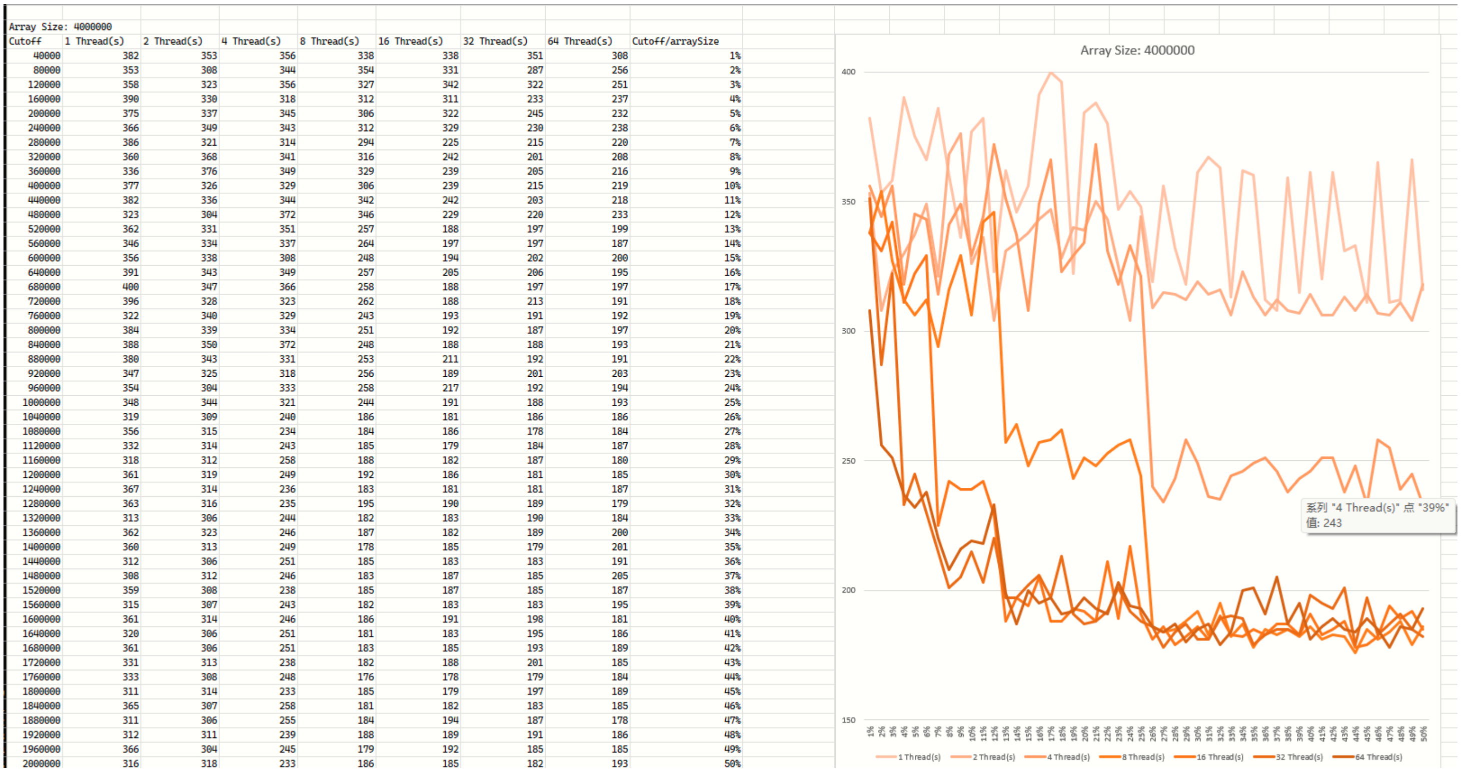
## Array Size 2,000,000



Array Size: 2000000

| Cutoff | 1 Thread(s) | 2 Thread(s) | 4 Thread(s) | 8 Thread(s) | 16 Thread(s) | 32 Thread(s) | 64 Thread(s) | Cutoff/arraySize |
|---|---|---|---|---|---|---|---|---|
| 20000 | 514 | 187 | 157 | 153 | 167 | 170 | 148 | 1% |
| 40000 | 246 | 177 | 180 | 148 | 150 | 153 | 118 | 2% |
| 60000 | 274 | 168 | 150 | 165 | 145 | 137 | 129 | 3% |
| 80000 | 289 | 165 | 174 | 160 | 161 | 106 | 109 | 4% |
| 100000 | 272 | 174 | 166 | 143 | 152 | 112 | 108 | 5% |
| 120000 | 171 | 174 | 172 | 173 | 138 | 106 | 117 | 6% |
| 140000 | 197 | 160 | 161 | 157 | 113 | 99 | 101 | 7% |
| 160000 | 185 | 179 | 176 | 150 | 114 | 106 | 100 | 8% |
| 180000 | 185 | 168 | 172 | 140 | 106 | 100 | 105 | 9% |
| 200000 | 180 | 176 | 157 | 153 | 112 | 95 | 101 | 10% |
| 220000 | 167 | 159 | 179 | 151 | 112 | 100 | 98 | 11% |
| 240000 | 182 | 177 | 158 | 150 | 107 | 104 | 97 | 12% |
| 260000 | 184 | 164 | 155 | 120 | 87 | 91 | 99 | 13% |
| 280000 | 171 | 181 | 145 | 122 | 94 | 95 | 97 | 14% |
| 300000 | 188 | 167 | 173 | 116 | 89 | 90 | 95 | 15% |
| 320000 | 172 | 161 | 158 | 116 | 97 | 88 | 90 | 16% |
| 340000 | 182 | 184 | 155 | 115 | 90 | 92 | 93 | 17% |
| 360000 | 198 | 155 | 149 | 116 | 96 | 94 | 95 | 18% |
| 380000 | 151 | 171 | 154 | 119 | 86 | 93 | 97 | 19% |
| 400000 | 170 | 173 | 159 | 122 | 86 | 87 | 91 | 20% |
| 420000 | 176 | 185 | 171 | 121 | 94 | 87 | 92 | 21% |
| 440000 | 191 | 174 | 177 | 119 | 101 | 91 | 90 | 22% |
| 460000 | 170 | 173 | 158 | 116 | 90 | 91 | 90 | 23% |
| 480000 | 193 | 177 | 143 | 120 | 86 | 91 | 91 | 24% |
| 500000 | 171 | 162 | 156 | 122 | 92 | 90 | 97 | 25% |
| 520000 | 155 | 152 | 112 | 88 | 87 | 83 | 86 | 26% |
| 540000 | 178 | 154 | 115 | 85 | 86 | 86 | 94 | 27% |
| 560000 | 179 | 152 | 116 | 85 | 88 | 84 | 86 | 28% |
| 580000 | 179 | 152 | 114 | 86 | 85 | 86 | 83 | 29% |
| 600000 | 196 | 167 | 112 | 83 | 85 | 90 | 87 | 30% |
| 620000 | 187 | 148 | 115 | 85 | 85 | 88 | 87 | 31% |
| 640000 | 179 | 148 | 117 | 84 | 83 | 86 | 87 | 32% |
| 660000 | 182 | 155 | 108 | 88 | 87 | 87 | 93 | 33% |
| 680000 | 177 | 146 | 111 | 87 | 84 | 88 | 85 | 34% |
| 700000 | 154 | 148 | 110 | 84 | 86 | 87 | 88 | 35% |
| 720000 | 177 | 152 | 113 | 87 | 84 | 85 | 97 | 36% |
| 740000 | 153 | 148 | 114 | 84 | 89 | 85 | 89 | 37% |
| 760000 | 177 | 149 | 116 | 85 | 86 | 88 | 87 | 38% |
| 780000 | 176 | 148 | 115 | 88 | 85 | 85 | 86 | 39% |
| 800000 | 154 | 151 | 120 | 85 | 86 | 93 | 87 | 40% |
| 820000 | 178 | 151 | 109 | 86 | 84 | 86 | 86 | 41% |
| 840000 | 180 | 148 | 111 | 84 | 82 | 85 | 86 | 42% |
| 860000 | 181 | 149 | 112 | 90 | 86 | 88 | 94 | 43% |
| 880000 | 153 | 150 | 120 | 87 | 82 | 84 | 87 | 44% |
| 900000 | 174 | 148 | 108 | 85 | 85 | 86 | 87 | 45% |
| 920000 | 176 | 151 | 119 | 85 | 92 | 86 | 85 | 46% |
| 940000 | 154 | 146 | 116 | 86 | 85 | 84 | 85 | 47% |
| 960000 | 152 | 148 | 115 | 83 | 85 | 85 | 86 | 48% |
| 980000 | 178 | 144 | 113 | 84 | 88 | 89 | 86 | 49% |
| 1000000 | 175 | 148 | 116 | 86 | 84 | 87 | 85 | 50% |

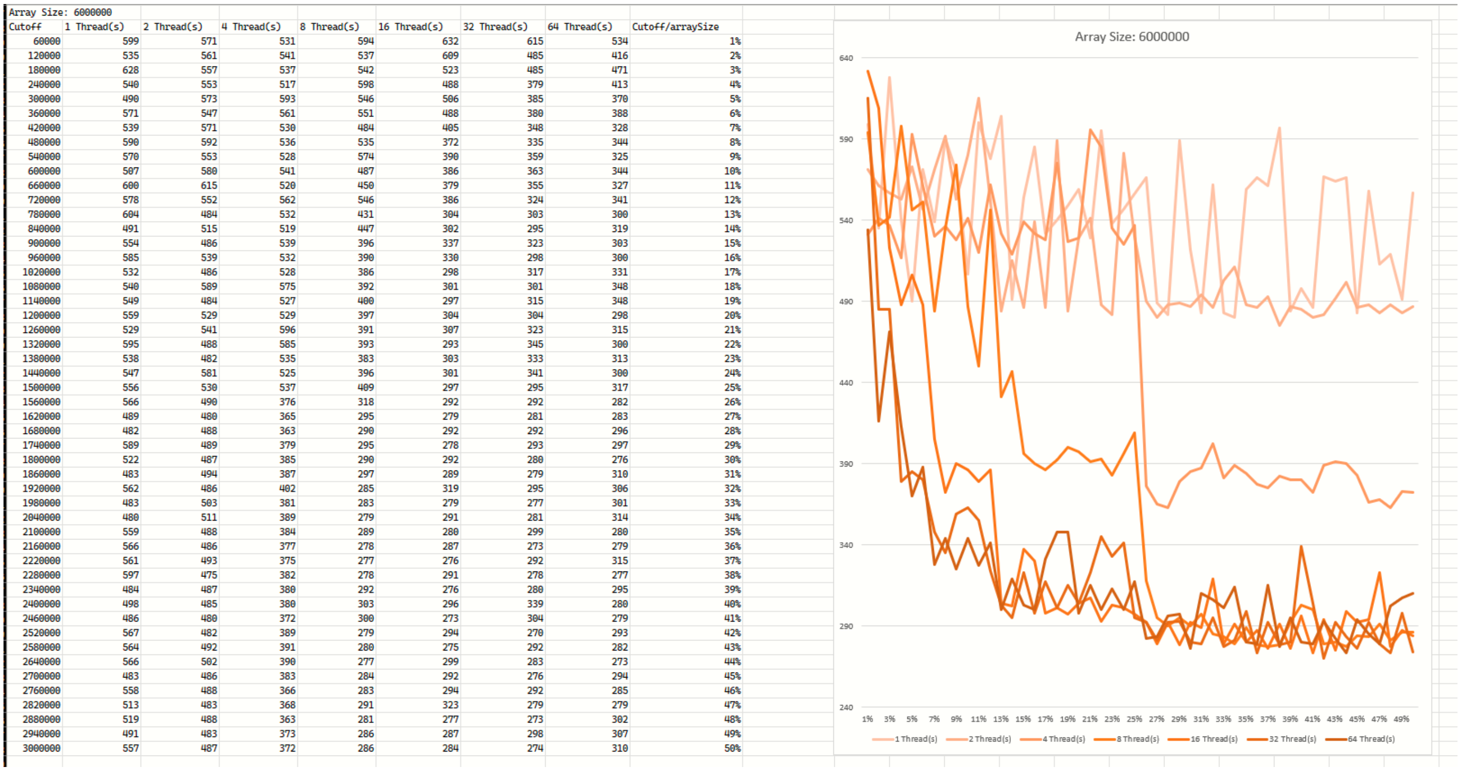
# Array Size 4,000,000



Array Size: 4000000

| Cutoff | 1 Thread(s) | 2 Thread(s) | 4 Thread(s) | 8 Thread(s) | 16 Thread(s) | 32 Thread(s) | 64 Thread(s) | Cutoff/arraySize |
|---|---|---|---|---|---|---|---|---|
| 40000 | 382 | 353 | 356 | 338 | 338 | 351 | 308 | 1% |
| 80000 | 353 | 308 | 344 | 354 | 331 | 287 | 256 | 2% |
| 120000 | 358 | 323 | 356 | 327 | 342 | 322 | 251 | 3% |
| 160000 | 390 | 330 | 318 | 312 | 311 | 233 | 237 | 4% |
| 200000 | 375 | 337 | 345 | 306 | 322 | 245 | 232 | 5% |
| 240000 | 366 | 349 | 343 | 312 | 329 | 230 | 238 | 6% |
| 280000 | 386 | 321 | 314 | 294 | 225 | 215 | 220 | 7% |
| 320000 | 360 | 368 | 341 | 316 | 242 | 201 | 208 | 8% |
| 360000 | 336 | 376 | 349 | 329 | 239 | 205 | 216 | 9% |
| 400000 | 377 | 326 | 329 | 306 | 239 | 215 | 219 | 10% |
| 440000 | 382 | 336 | 344 | 342 | 242 | 203 | 218 | 11% |
| 480000 | 323 | 304 | 372 | 346 | 229 | 220 | 233 | 12% |
| 520000 | 362 | 331 | 351 | 257 | 188 | 197 | 199 | 13% |
| 560000 | 346 | 334 | 337 | 264 | 197 | 197 | 187 | 14% |
| 600000 | 356 | 338 | 308 | 248 | 194 | 202 | 200 | 15% |
| 640000 | 391 | 343 | 349 | 257 | 205 | 206 | 195 | 16% |
| 680000 | 400 | 347 | 366 | 258 | 188 | 197 | 197 | 17% |
| 720000 | 396 | 328 | 323 | 262 | 188 | 213 | 191 | 18% |
| 760000 | 322 | 340 | 329 | 243 | 193 | 191 | 192 | 19% |
| 800000 | 384 | 339 | 334 | 251 | 192 | 187 | 197 | 20% |
| 840000 | 388 | 350 | 372 | 248 | 188 | 188 | 193 | 21% |
| 880000 | 380 | 343 | 331 | 253 | 211 | 192 | 191 | 22% |
| 920000 | 347 | 325 | 318 | 256 | 189 | 201 | 203 | 23% |
| 960000 | 354 | 304 | 333 | 258 | 217 | 192 | 194 | 24% |
| 1000000 | 348 | 344 | 321 | 244 | 191 | 188 | 193 | 25% |
| 1040000 | 319 | 309 | 240 | 186 | 181 | 186 | 186 | 26% |
| 1080000 | 356 | 315 | 234 | 184 | 186 | 178 | 184 | 27% |
| 1120000 | 332 | 314 | 243 | 185 | 179 | 184 | 187 | 28% |
| 1160000 | 318 | 312 | 258 | 188 | 182 | 187 | 180 | 29% |
| 1200000 | 361 | 319 | 249 | 192 | 186 | 181 | 185 | 30% |
| 1240000 | 367 | 314 | 236 | 183 | 181 | 181 | 187 | 31% |
| 1280000 | 363 | 316 | 235 | 195 | 190 | 189 | 179 | 32% |
| 1320000 | 313 | 306 | 244 | 182 | 183 | 190 | 184 | 33% |
| 1360000 | 362 | 323 | 246 | 187 | 182 | 189 | 200 | 34% |
| 1400000 | 360 | 313 | 249 | 178 | 185 | 179 | 201 | 35% |
| 1440000 | 312 | 306 | 251 | 185 | 183 | 183 | 191 | 36% |
| 1480000 | 308 | 312 | 246 | 183 | 187 | 185 | 205 | 37% |
| 1520000 | 359 | 308 | 238 | 185 | 187 | 185 | 187 | 38% |
| 1560000 | 315 | 307 | 243 | 182 | 183 | 183 | 195 | 39% |
| 1600000 | 361 | 314 | 246 | 186 | 191 | 198 | 181 | 40% |
| 1640000 | 320 | 306 | 251 | 181 | 183 | 195 | 186 | 41% |
| 1680000 | 361 | 306 | 251 | 183 | 185 | 193 | 189 | 42% |
| 1720000 | 331 | 313 | 238 | 182 | 188 | 201 | 185 | 43% |
| 1760000 | 333 | 308 | 248 | 176 | 178 | 179 | 184 | 44% |
| 1800000 | 311 | 314 | 233 | 185 | 179 | 197 | 189 | 45% |
| 1840000 | 365 | 307 | 258 | 181 | 182 | 183 | 185 | 46% |
| 1880000 | 311 | 306 | 255 | 184 | 194 | 187 | 178 | 47% |
| 1920000 | 312 | 311 | 239 | 188 | 189 | 191 | 186 | 48% |
| 1960000 | 366 | 304 | 245 | 179 | 192 | 185 | 185 | 49% |
| 2000000 | 316 | 318 | 233 | 186 | 185 | 182 | 193 | 50% |

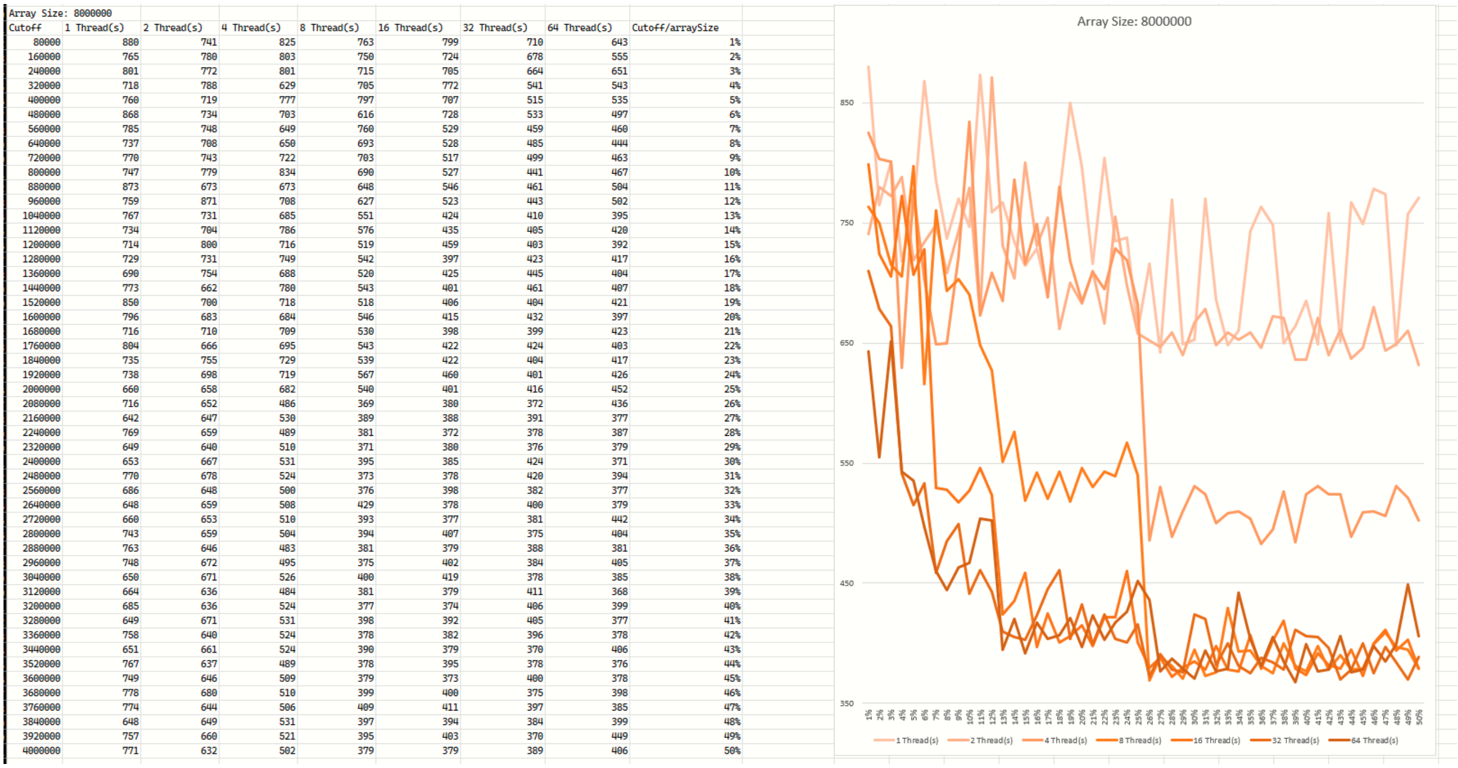
# Array Size 6,000,000



Array Size: 6000000

| Cutoff | 1 Thread(s) | 2 Thread(s) | 4 Thread(s) | 8 Thread(s) | 16 Thread(s) | 32 Thread(s) | 64 Thread(s) | Cutoff/arraySize |
|---|---|---|---|---|---|---|---|---|
| 60000 | 599 | 571 | 531 | 594 | 632 | 615 | 534 | 1% |
| 120000 | 535 | 561 | 541 | 537 | 609 | 485 | 416 | 2% |
| 180000 | 628 | 557 | 537 | 542 | 523 | 485 | 471 | 3% |
| 240000 | 540 | 553 | 517 | 598 | 488 | 379 | 413 | 4% |
| 300000 | 490 | 573 | 593 | 546 | 506 | 385 | 370 | 5% |
| 360000 | 571 | 547 | 561 | 551 | 488 | 380 | 388 | 6% |
| 420000 | 539 | 571 | 530 | 484 | 405 | 348 | 328 | 7% |
| 480000 | 590 | 592 | 536 | 535 | 372 | 335 | 344 | 8% |
| 540000 | 570 | 553 | 528 | 574 | 390 | 359 | 325 | 9% |
| 600000 | 507 | 580 | 541 | 487 | 386 | 363 | 344 | 10% |
| 660000 | 600 | 615 | 520 | 450 | 379 | 355 | 327 | 11% |
| 720000 | 578 | 552 | 562 | 546 | 386 | 324 | 341 | 12% |
| 780000 | 604 | 484 | 532 | 431 | 304 | 303 | 300 | 13% |
| 840000 | 491 | 515 | 519 | 447 | 302 | 295 | 319 | 14% |
| 900000 | 554 | 486 | 539 | 396 | 337 | 323 | 303 | 15% |
| 960000 | 585 | 539 | 532 | 390 | 330 | 298 | 300 | 16% |
| 1020000 | 532 | 486 | 528 | 386 | 298 | 317 | 331 | 17% |
| 1080000 | 540 | 589 | 575 | 392 | 301 | 301 | 348 | 18% |
| 1140000 | 549 | 484 | 527 | 400 | 297 | 315 | 348 | 19% |
| 1200000 | 559 | 529 | 529 | 397 | 304 | 304 | 298 | 20% |
| 1260000 | 529 | 541 | 596 | 391 | 307 | 323 | 315 | 21% |
| 1320000 | 595 | 488 | 585 | 393 | 293 | 345 | 300 | 22% |
| 1380000 | 538 | 482 | 535 | 383 | 303 | 333 | 313 | 23% |
| 1440000 | 547 | 581 | 525 | 396 | 301 | 341 | 300 | 24% |
| 1500000 | 556 | 530 | 537 | 409 | 297 | 295 | 317 | 25% |
| 1560000 | 566 | 490 | 376 | 318 | 292 | 292 | 282 | 26% |
| 1620000 | 489 | 480 | 365 | 295 | 279 | 281 | 283 | 27% |
| 1680000 | 482 | 488 | 363 | 290 | 292 | 292 | 296 | 28% |
| 1740000 | 589 | 489 | 379 | 295 | 278 | 293 | 297 | 29% |
| 1800000 | 522 | 487 | 385 | 290 | 292 | 280 | 276 | 30% |
| 1860000 | 483 | 494 | 387 | 297 | 289 | 279 | 310 | 31% |
| 1920000 | 562 | 486 | 402 | 285 | 319 | 295 | 306 | 32% |
| 1980000 | 483 | 503 | 381 | 283 | 279 | 277 | 301 | 33% |
| 2040000 | 480 | 511 | 389 | 279 | 291 | 281 | 314 | 34% |
| 2100000 | 559 | 488 | 384 | 289 | 280 | 299 | 280 | 35% |
| 2160000 | 566 | 486 | 377 | 278 | 287 | 273 | 279 | 36% |
| 2220000 | 561 | 493 | 375 | 277 | 276 | 292 | 315 | 37% |
| 2280000 | 597 | 475 | 382 | 278 | 291 | 278 | 277 | 38% |
| 2340000 | 484 | 487 | 380 | 292 | 276 | 280 | 295 | 39% |
| 2400000 | 498 | 485 | 380 | 303 | 296 | 339 | 280 | 40% |
| 2460000 | 486 | 480 | 372 | 300 | 273 | 304 | 279 | 41% |
| 2520000 | 567 | 482 | 389 | 279 | 294 | 270 | 293 | 42% |
| 2580000 | 564 | 492 | 391 | 280 | 275 | 292 | 282 | 43% |
| 2640000 | 566 | 502 | 390 | 277 | 299 | 283 | 273 | 44% |
| 2700000 | 483 | 486 | 383 | 284 | 292 | 276 | 294 | 45% |
| 2760000 | 558 | 488 | 366 | 283 | 294 | 292 | 285 | 46% |
| 2820000 | 513 | 483 | 368 | 291 | 323 | 279 | 279 | 47% |
| 2880000 | 519 | 488 | 363 | 281 | 277 | 273 | 302 | 48% |
| 2940000 | 491 | 483 | 373 | 286 | 287 | 298 | 307 | 49% |
| 3000000 | 557 | 487 | 372 | 286 | 284 | 274 | 310 | 50% |

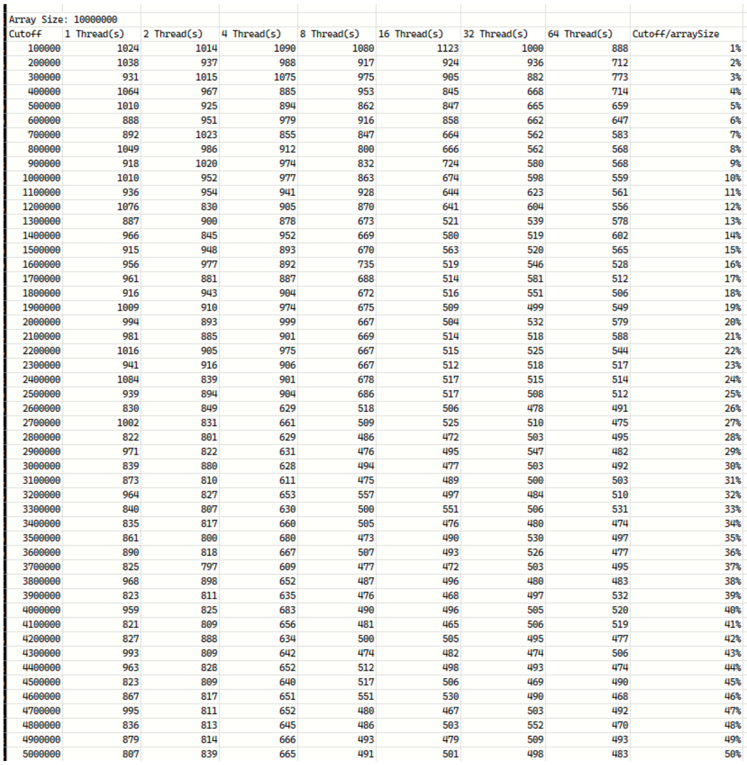
# Array Size 8,000,000



Array Size: 8000000

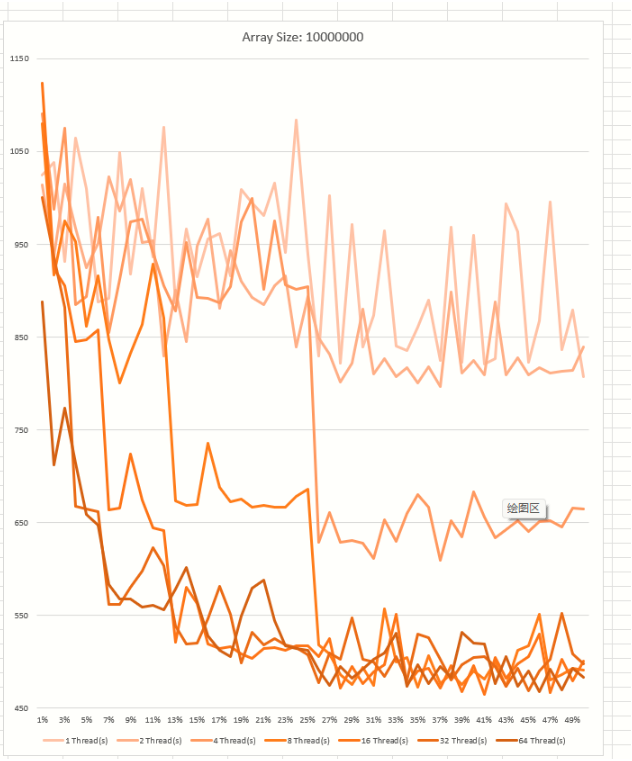
| Cutoff | 1 Thread(s) | 2 Thread(s) | 4 Thread(s) | 8 Thread(s) | 16 Thread(s) | 32 Thread(s) | 64 Thread(s) | Cutoff/arraySize |
|---|---|---|---|---|---|---|---|---|
| 80000 | 880 | 741 | 825 | 763 | 799 | 710 | 643 | 1% |
| 160000 | 765 | 780 | 803 | 750 | 724 | 678 | 555 | 2% |
| 240000 | 801 | 772 | 801 | 715 | 705 | 664 | 651 | 3% |
| 320000 | 718 | 788 | 629 | 705 | 772 | 541 | 543 | 4% |
| 400000 | 760 | 719 | 777 | 797 | 707 | 515 | 535 | 5% |
| 480000 | 868 | 734 | 703 | 616 | 728 | 533 | 497 | 6% |
| 560000 | 785 | 748 | 649 | 760 | 529 | 459 | 460 | 7% |
| 640000 | 737 | 708 | 650 | 693 | 528 | 485 | 444 | 8% |
| 720000 | 770 | 743 | 722 | 703 | 517 | 499 | 463 | 9% |
| 800000 | 747 | 779 | 834 | 690 | 527 | 441 | 467 | 10% |
| 880000 | 873 | 673 | 673 | 648 | 546 | 461 | 504 | 11% |
| 960000 | 759 | 871 | 708 | 627 | 523 | 443 | 502 | 12% |
| 1040000 | 767 | 731 | 685 | 551 | 424 | 410 | 395 | 13% |
| 1120000 | 734 | 704 | 786 | 576 | 435 | 405 | 420 | 14% |
| 1200000 | 714 | 800 | 716 | 519 | 459 | 403 | 392 | 15% |
| 1280000 | 729 | 731 | 749 | 542 | 397 | 423 | 417 | 16% |
| 1360000 | 690 | 754 | 688 | 520 | 425 | 445 | 404 | 17% |
| 1440000 | 773 | 662 | 780 | 543 | 401 | 461 | 407 | 18% |
| 1520000 | 850 | 700 | 718 | 518 | 406 | 404 | 421 | 19% |
| 1600000 | 796 | 683 | 684 | 546 | 415 | 432 | 397 | 20% |
| 1680000 | 716 | 710 | 709 | 530 | 398 | 399 | 423 | 21% |
| 1760000 | 804 | 666 | 695 | 543 | 422 | 424 | 403 | 22% |
| 1840000 | 735 | 755 | 729 | 539 | 422 | 404 | 417 | 23% |
| 1920000 | 738 | 698 | 719 | 567 | 460 | 401 | 426 | 24% |
| 2000000 | 660 | 658 | 682 | 540 | 401 | 416 | 452 | 25% |
| 2080000 | 716 | 652 | 486 | 369 | 380 | 372 | 436 | 26% |
| 2160000 | 642 | 647 | 530 | 389 | 388 | 391 | 377 | 27% |
| 2240000 | 769 | 659 | 489 | 381 | 372 | 378 | 387 | 28% |
| 2320000 | 649 | 640 | 510 | 371 | 380 | 376 | 379 | 29% |
| 2400000 | 653 | 667 | 531 | 395 | 385 | 424 | 371 | 30% |
| 2480000 | 770 | 678 | 524 | 373 | 378 | 420 | 394 | 31% |
| 2560000 | 686 | 648 | 500 | 376 | 398 | 382 | 377 | 32% |
| 2640000 | 648 | 659 | 508 | 429 | 378 | 400 | 379 | 33% |
| 2720000 | 660 | 653 | 510 | 393 | 377 | 381 | 442 | 34% |
| 2800000 | 743 | 659 | 504 | 394 | 407 | 375 | 404 | 35% |
| 2880000 | 763 | 646 | 483 | 381 | 379 | 388 | 381 | 36% |
| 2960000 | 748 | 672 | 495 | 375 | 402 | 384 | 405 | 37% |
| 3040000 | 650 | 671 | 526 | 400 | 419 | 378 | 385 | 38% |
| 3120000 | 664 | 636 | 484 | 381 | 379 | 411 | 368 | 39% |
| 3200000 | 685 | 636 | 524 | 377 | 374 | 406 | 399 | 40% |
| 3280000 | 649 | 671 | 531 | 398 | 392 | 405 | 377 | 41% |
| 3360000 | 758 | 640 | 524 | 378 | 382 | 396 | 378 | 42% |
| 3440000 | 651 | 661 | 524 | 390 | 379 | 370 | 406 | 43% |
| 3520000 | 767 | 637 | 489 | 378 | 395 | 378 | 376 | 44% |
| 3600000 | 749 | 646 | 509 | 379 | 373 | 400 | 378 | 45% |
| 3680000 | 778 | 680 | 510 | 399 | 400 | 375 | 398 | 46% |
| 3760000 | 774 | 644 | 506 | 409 | 411 | 397 | 385 | 47% |
| 3840000 | 648 | 649 | 531 | 397 | 394 | 384 | 399 | 48% |
| 3920000 | 757 | 660 | 521 | 395 | 403 | 370 | 449 | 49% |
| 4000000 | 771 | 632 | 502 | 379 | 379 | 389 | 406 | 50% |

# Array Size 10,000,000



Array Size: 10000000

| Cutoff | 1 Thread(s) | 2 Thread(s) | 4 Thread(s) | 8 Thread(s) | 16 Thread(s) | 32 Thread(s) | 64 Thread(s) | Cutoff/arraySize |
|---|---|---|---|---|---|---|---|---|
| 100000 | 1024 | 1014 | 1090 | 1080 | 1123 | 1000 | 888 | 1% |
| 200000 | 1038 | 937 | 988 | 917 | 924 | 936 | 712 | 2% |
| 300000 | 931 | 1015 | 1075 | 975 | 905 | 882 | 773 | 3% |
| 400000 | 1064 | 967 | 885 | 953 | 845 | 668 | 714 | 4% |
| 500000 | 1010 | 925 | 894 | 862 | 847 | 665 | 659 | 5% |
| 600000 | 888 | 951 | 979 | 916 | 858 | 662 | 647 | 6% |
| 700000 | 892 | 1023 | 855 | 847 | 664 | 562 | 583 | 7% |
| 800000 | 1049 | 986 | 912 | 800 | 666 | 562 | 568 | 8% |
| 900000 | 918 | 1020 | 974 | 832 | 724 | 580 | 568 | 9% |
| 1000000 | 1010 | 952 | 977 | 863 | 674 | 598 | 559 | 10% |
| 1100000 | 936 | 954 | 941 | 928 | 644 | 623 | 561 | 11% |
| 1200000 | 1076 | 830 | 905 | 870 | 641 | 604 | 556 | 12% |
| 1300000 | 887 | 900 | 878 | 673 | 521 | 539 | 578 | 13% |
| 1400000 | 966 | 845 | 952 | 669 | 580 | 519 | 602 | 14% |
| 1500000 | 915 | 948 | 893 | 670 | 563 | 520 | 565 | 15% |
| 1600000 | 956 | 977 | 892 | 735 | 519 | 546 | 528 | 16% |
| 1700000 | 961 | 881 | 887 | 688 | 514 | 581 | 512 | 17% |
| 1800000 | 916 | 943 | 904 | 672 | 516 | 551 | 506 | 18% |
| 1900000 | 1009 | 910 | 974 | 675 | 509 | 499 | 549 | 19% |
| 2000000 | 994 | 893 | 999 | 667 | 504 | 532 | 579 | 20% |
| 2100000 | 981 | 885 | 901 | 669 | 514 | 518 | 588 | 21% |
| 2200000 | 1016 | 905 | 975 | 667 | 515 | 525 | 544 | 22% |
| 2300000 | 941 | 916 | 906 | 667 | 512 | 518 | 517 | 23% |
| 2400000 | 1084 | 839 | 901 | 678 | 517 | 515 | 514 | 24% |
| 2500000 | 939 | 894 | 904 | 686 | 517 | 508 | 512 | 25% |
| 2600000 | 830 | 849 | 629 | 518 | 506 | 478 | 491 | 26% |
| 2700000 | 1002 | 831 | 661 | 509 | 525 | 510 | 475 | 27% |
| 2800000 | 822 | 801 | 629 | 486 | 472 | 503 | 495 | 28% |
| 2900000 | 971 | 822 | 631 | 476 | 495 | 547 | 482 | 29% |
| 3000000 | 839 | 880 | 628 | 494 | 477 | 503 | 492 | 30% |
| 3100000 | 873 | 810 | 611 | 475 | 489 | 500 | 503 | 31% |
| 3200000 | 964 | 827 | 653 | 557 | 497 | 484 | 510 | 32% |
| 3300000 | 840 | 807 | 630 | 500 | 551 | 506 | 531 | 33% |
| 3400000 | 835 | 817 | 660 | 505 | 476 | 480 | 474 | 34% |
| 3500000 | 861 | 800 | 680 | 473 | 490 | 530 | 497 | 35% |
| 3600000 | 890 | 818 | 667 | 507 | 493 | 526 | 477 | 36% |
| 3700000 | 825 | 797 | 609 | 477 | 472 | 503 | 495 | 37% |
| 3800000 | 968 | 898 | 652 | 487 | 496 | 480 | 483 | 38% |
| 3900000 | 823 | 811 | 635 | 476 | 468 | 497 | 532 | 39% |
| 4000000 | 959 | 825 | 683 | 490 | 496 | 505 | 520 | 40% |
| 4100000 | 821 | 809 | 656 | 481 | 465 | 506 | 519 | 41% |
| 4200000 | 827 | 888 | 634 | 500 | 505 | 495 | 477 | 42% |
| 4300000 | 993 | 809 | 642 | 474 | 482 | 474 | 506 | 43% |
| 4400000 | 963 | 828 | 652 | 512 | 498 | 493 | 474 | 44% |
| 4500000 | 823 | 809 | 640 | 517 | 506 | 469 | 490 | 45% |
| 4600000 | 867 | 817 | 651 | 551 | 530 | 490 | 468 | 46% |
| 4700000 | 995 | 811 | 652 | 480 | 467 | 503 | 492 | 47% |
| 4800000 | 836 | 813 | 645 | 486 | 503 | 552 | 470 | 48% |
| 4900000 | 879 | 814 | 666 | 493 | 479 | 509 | 493 | 49% |
| 5000000 | 807 | 839 | 665 | 491 | 501 | 498 | 483 | 50% |



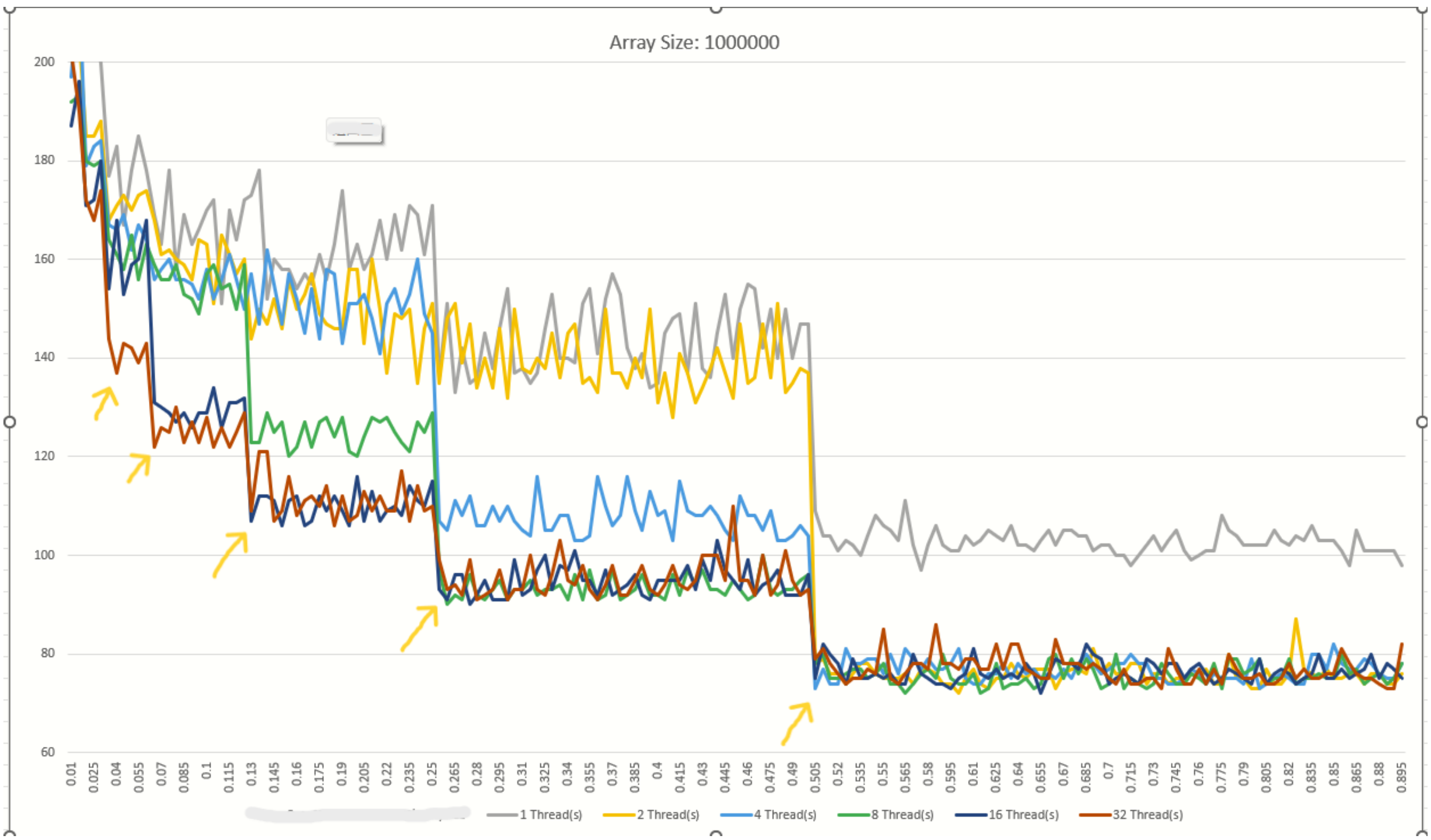
# Observation

In the chart above, we can see the cutoff value is above 25% of arraysize, the parallel sorting proformence better than cutoff value smaller than 25% of arraysize.

For number of threads, it seems that the more threads we have the faster the algorthm sort the array. For threads number more than 16, there is no obvious difference.

# More Observation

Then I try to extent the percentage of array size as cutoff value (1% - 90%) to see how cutoff value effect sorting speed.



In some intervals of cutoff values, the sorting time tends to be stable.

(50% - 100%], (25% - 50], (12.5% - 25%],(6.25%,-12.5%] ...

in generally, this interval is where

The larger n, the lower the efficiency of sorting. When the cutoff value is greater than 50% of the array size, the sorting efficiency is the highest and tends to be stable.

Multithreading is always more efficient than single threading. When the number of threads is greater than or equal to 2, the increase of threads will bring more obvious improvement when the cutoff value is lower. As the cutoff value increases, the improvement brought by increasing the number of threads is not obvious

# Conclusion

Since we are using a merge sort strategy, this strategy requires dividing the array into halfs. The number of dividing operation depends on the cutoff value. This results in increasing the dividing operation to times when the cutoff is less than , where . This is why the sorting time is different between the previously mentioned intervals

When the cutoff value is smaller, in an other word when there are more partitions. Using more threads results in significant performance gains. However, whenever two adjacent partition are sorted and merged, some threads will be idle and not participate in the rest of the sorting. So when the cutoff value is too small, the sorting efficiency is low.

Since our algorithm will split the array into two parts at least once. when the cutoff value is large, there will be two threads participating in the sorting, and the remaining threads will be idle, which will result in when the cutoff is greater than 50% of the array size, no matter how many threads we set, the algorithm efficiency are not improved.

For parallel sorting, the best strategy is to **set the cutoff value greater than 50% of the array size, and use two threads.**

## possible improvement

make those idle threads participate in soring rest of the array.