Implementation of
Controlled Random Search Algorithm

in sequential version
and
parallel version with OpenMP

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Outlines

1. The description of problem
2. Controlled Random Search Algorithm
3. Sequential Implementation
4. Parallel Implementation
5. Evaluation of two versions

1. The description of problem

Solve the optimization problem for n=10, 50, 100.

$$\min_x \left[f(x) = \frac{1}{40} \sum_{i=1}^{n} x_i^2 + 1 - \prod_{i=1}^{n} \cos\left(\frac{x_i}{i}\right) \right]$$

where D=$\{ x_i$: -40 < x_i < 40$\}$, n – entered as a program argument.
STOP CRITERION: take ε= 0.001.

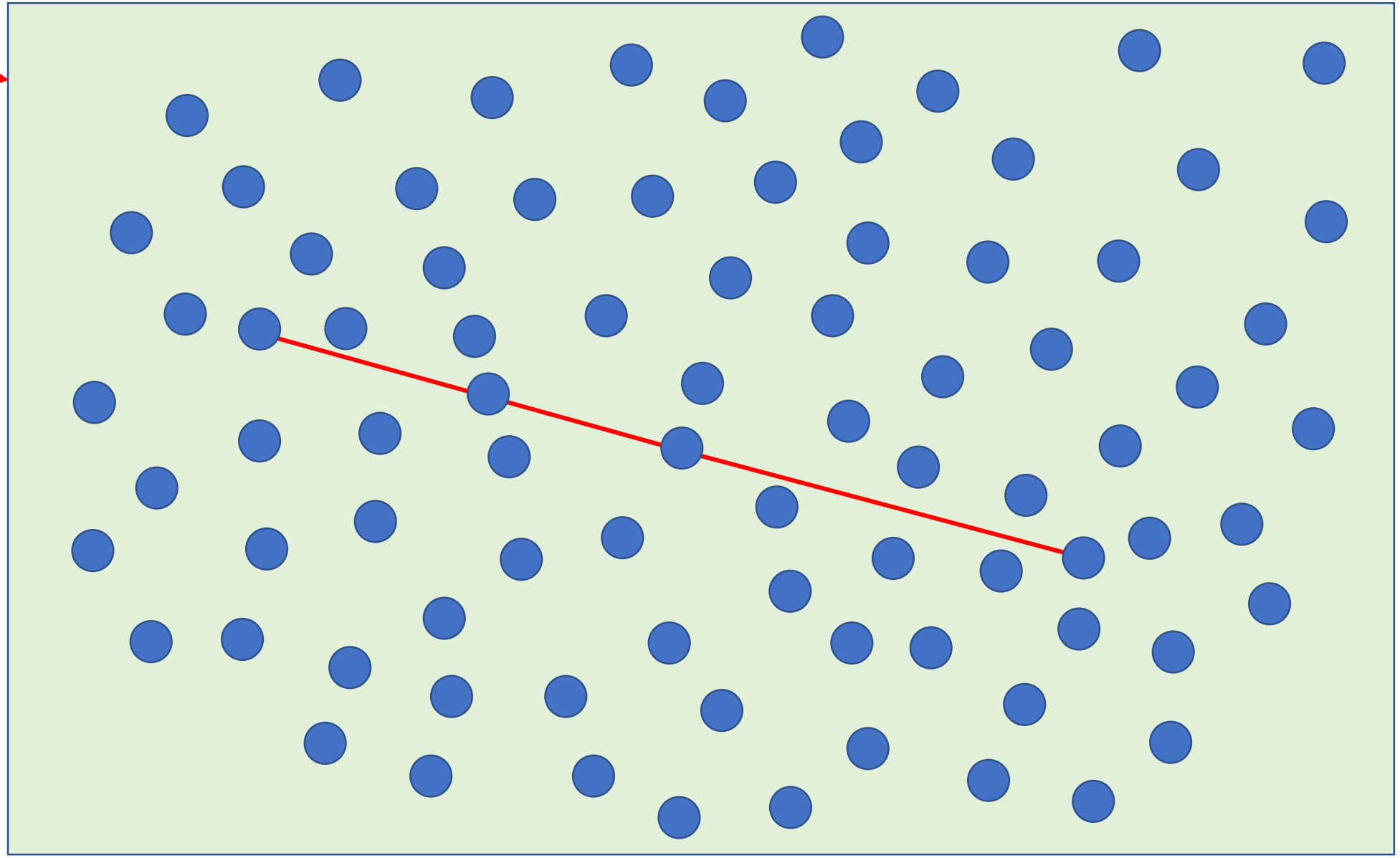
Environment wherein project was conducted:
Laptop: Intel Core i5-3230, 2 Cores, 4 Logical Processors

2. Controlled Random Search Algorithm

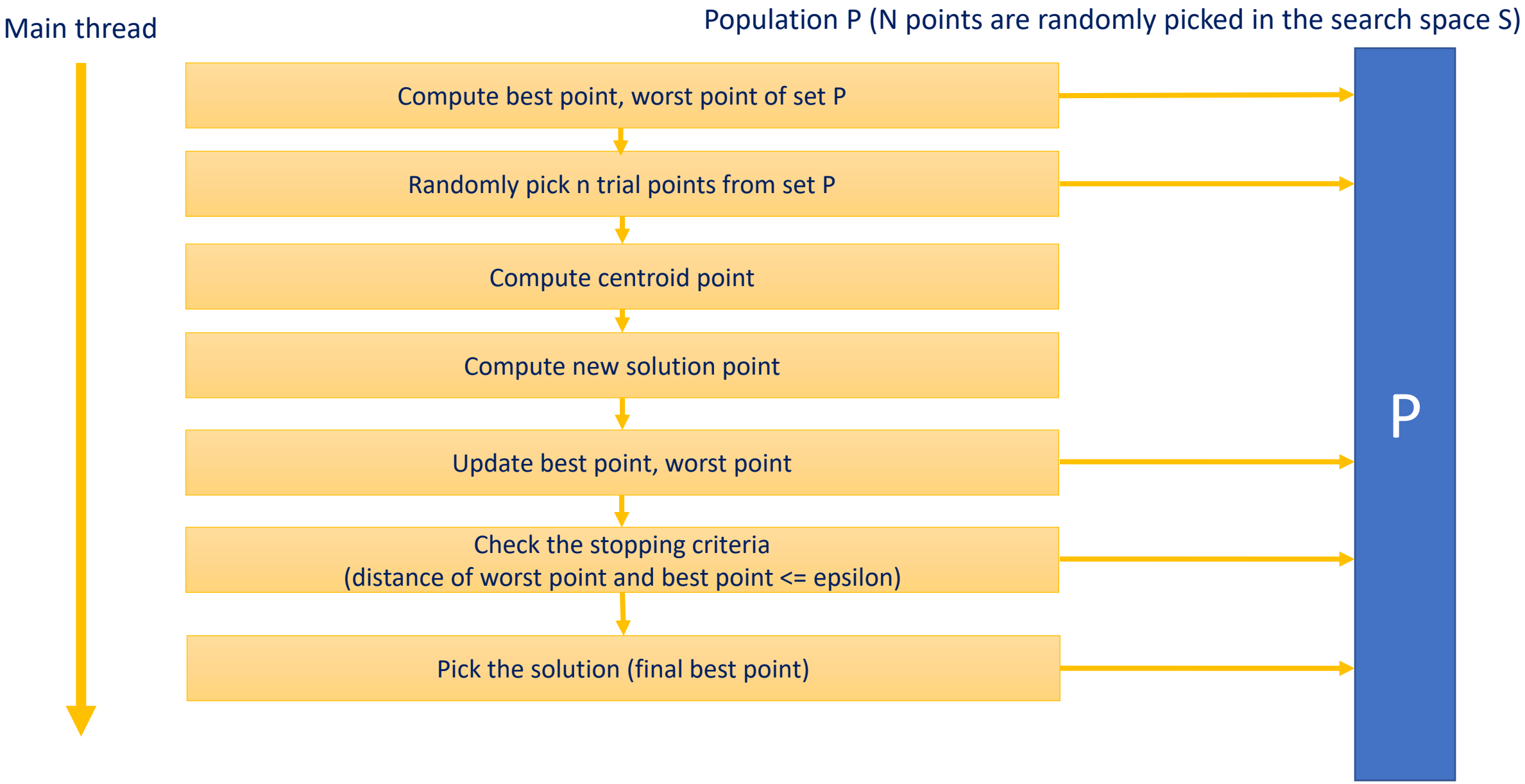
1. Search Space S

2. Objective function F(x)
   Best point < … < Worst point

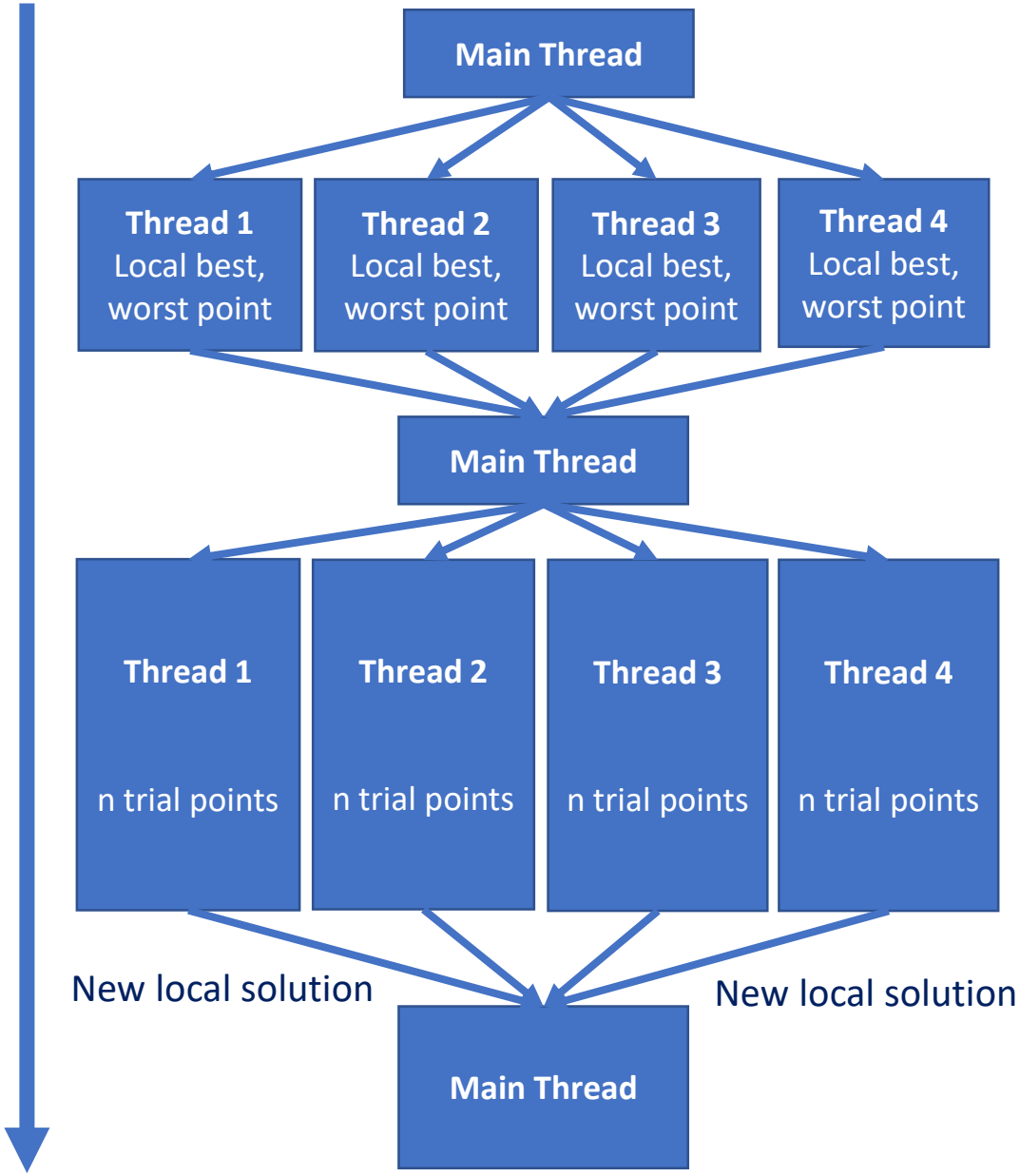
3. LOOP:
   - Randomly pick n points
   - Compute centroid
   - Compute new solution:
     (2 possible points)
   - Replace worst point by
     new solution point
   - Until converging at the
     solution point

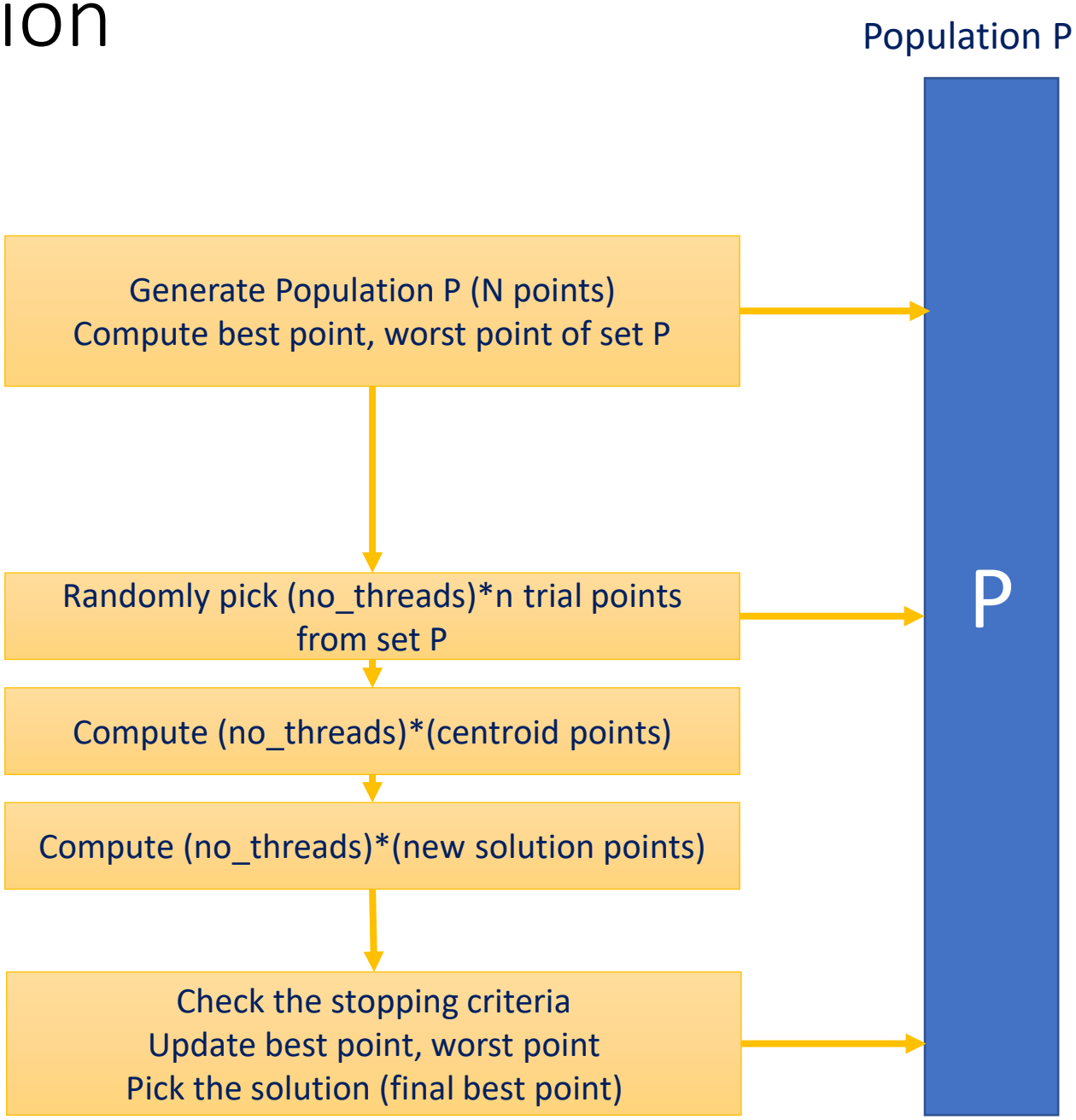


3. Sequential Implementation

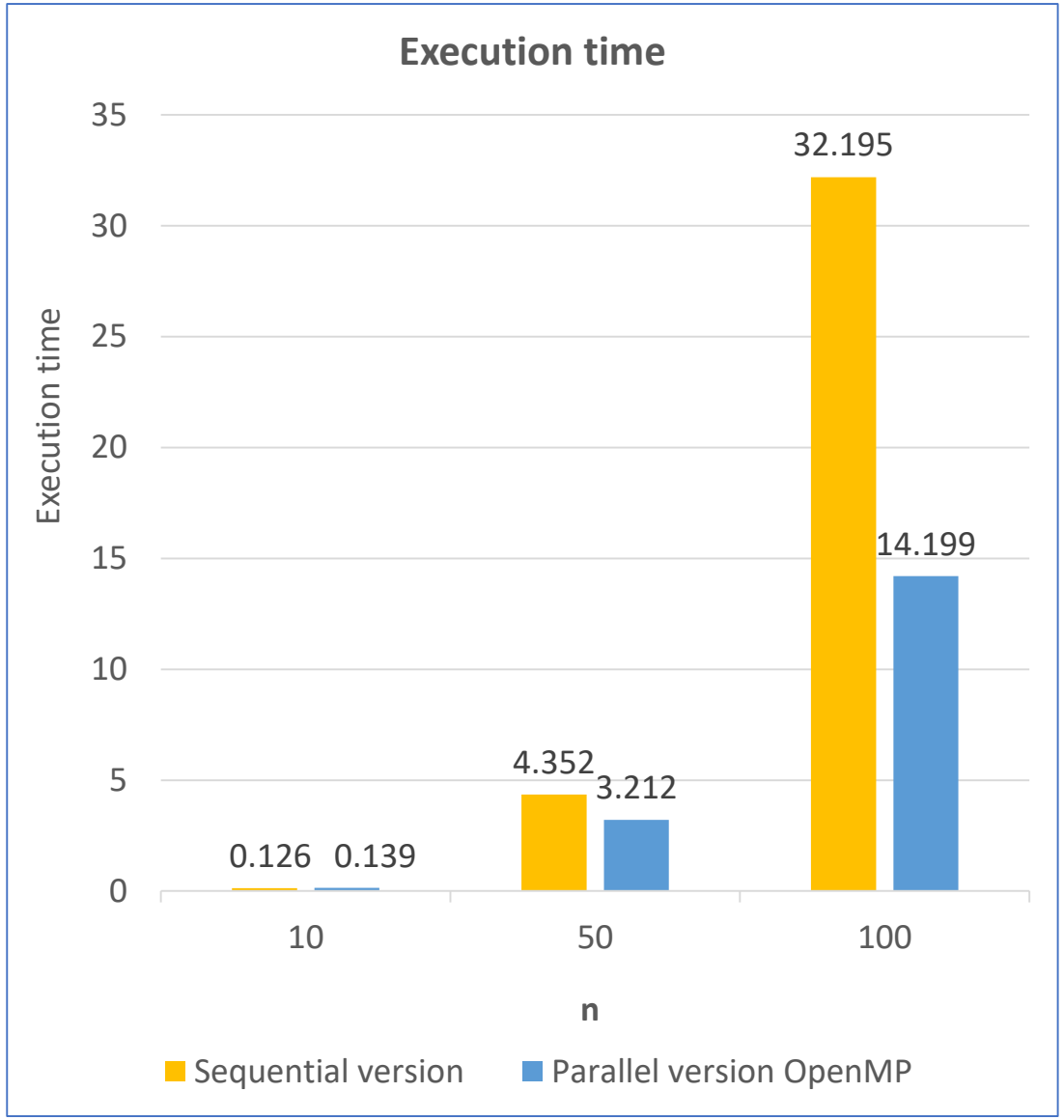


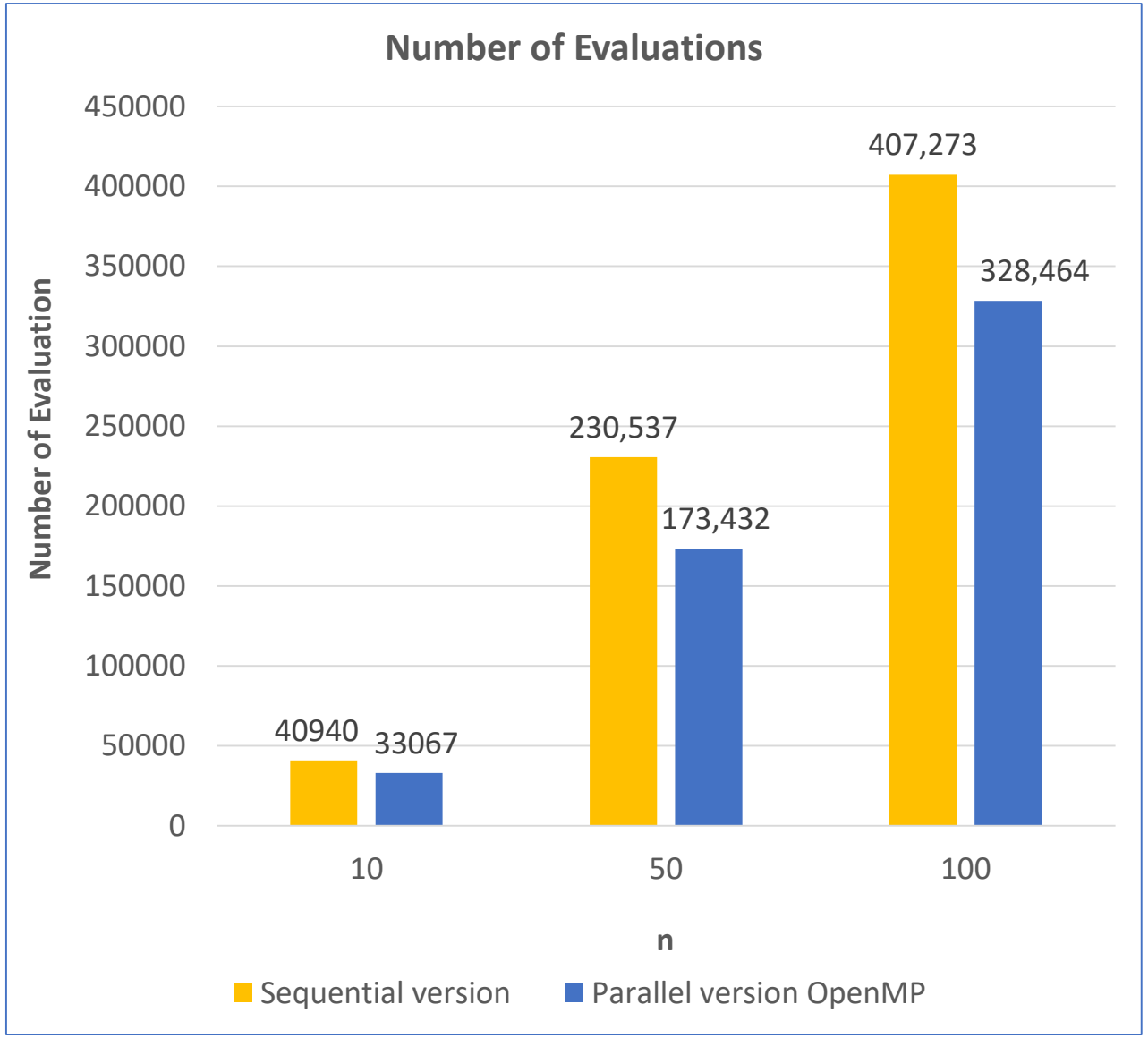
4. Parallel Implementation





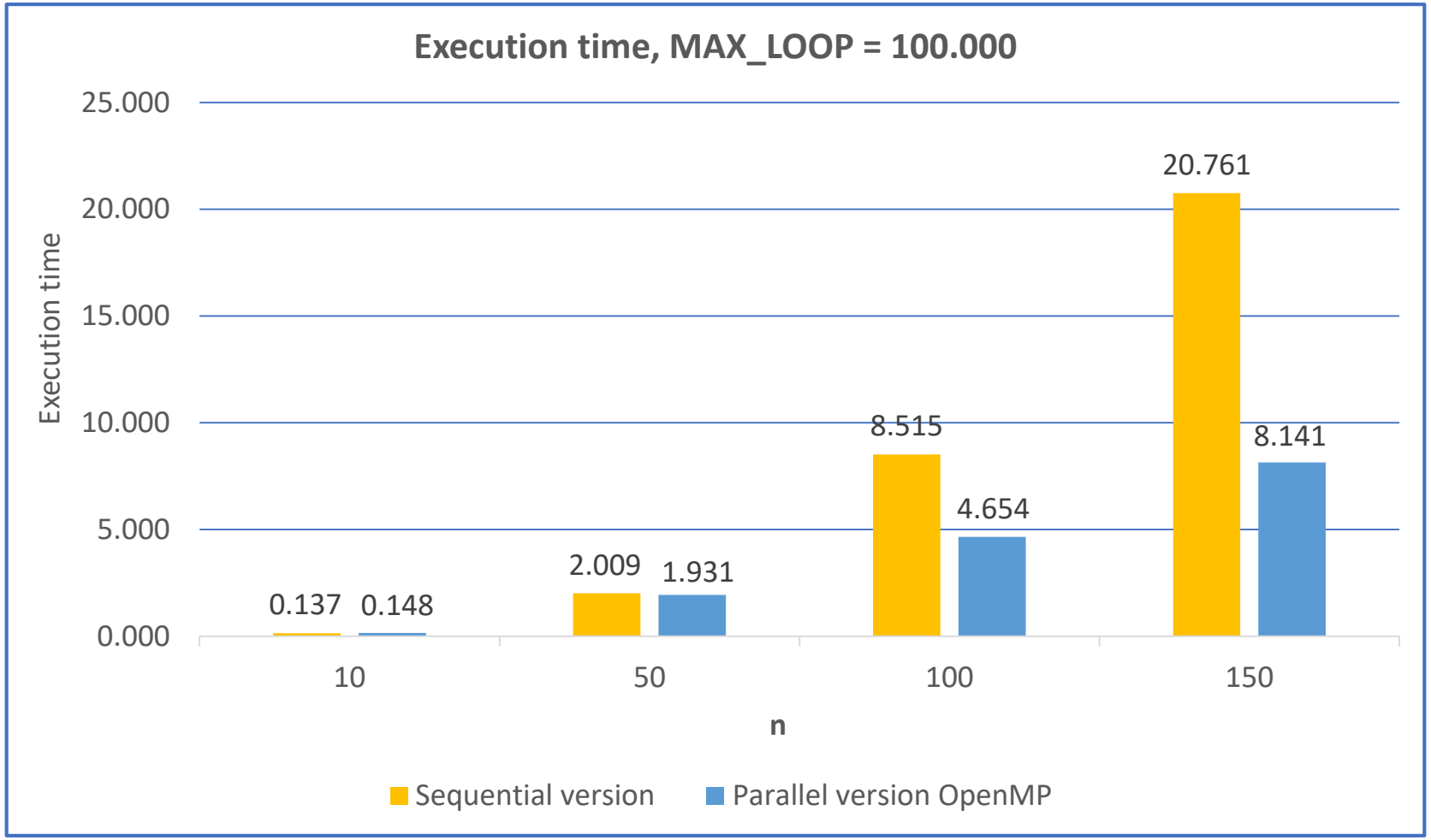
5. Evaluation of two versions





5. Evaluation of two versions – MAX_LOOP=100.000

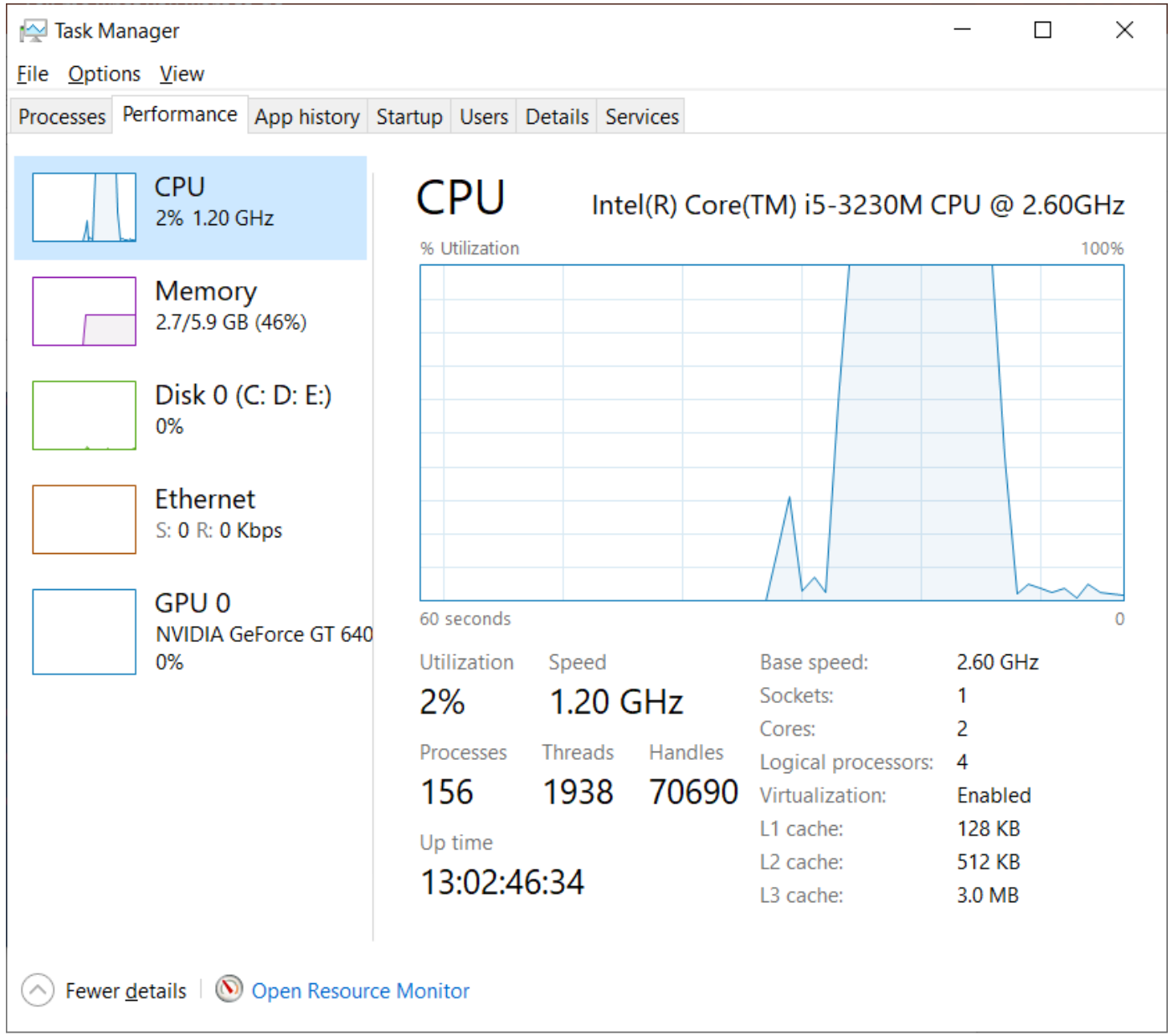
Execution time, MAX_LOOP = 100.000				
n	10	50	100	150
Sequential version	0.137	2.009	8.515	20.761
Parallel version OpenMP	0.148	1.931	4.654	8.141



Experiments

Number of tries	Siquential version		Parallel version	
	Execution time	Number of evaluations	Execution time	Number of evaluations
n=10				
1	0.122732	39528	0.134342	32174
2	0.135257	41161	0.129385	31918
3	0.123017	41000	0.135689	31566
4	0.130692	41597	0.14785	34198
5	0.120198	41416	0.147518	35478
Average:	0.126	40,940	0.139	33,067
n=50				
1	4.05527	213911	3.55302	180598
2	4.65267	253733	3.00756	162582
3	4.37481	232257	3.25768	180390
4	4.35309	232587	3.2388	179030
5	4.32195	220196	3.00262	164558
Average:	4.352	230,537	3.212	173,432
n=100				
1	33.4628	430665	14.8626	341042
2	31.3941	397422	13.0918	303506
3	32.1889	399076	13.3524	306530
4	33.0657	423313	15.3713	357122
5	30.864	385889	14.3166	334122
Average:	32.195	407,273	14.199	328,464

n	Statistics	Sequential version	Parallel version OpenMP
10	Execution time	0.126	0.139
	Number of evaluations	40940	33067
50	Execution time	4.352	3.212
	Number of evaluations	230,537	173,432
100	Execution time	32.195	14.199
	Number of evaluations	407,273	328,464


Task Manager
File Options View
Processes Performance App history Startup Users Details Services
CPU
2% 1.20 GHz
Memory
2.7/5.9 GB (46%)
Disk 0 (C: D: E:)
0%
Ethernet
S: 0 R: 0 Kbps
GPU 0
NVIDIA GeForce GT 640
0%
CPU
Intel(R) Core(TM) i5-3230M CPU @ 2.60GHz
% Utilization
100%
60 seconds
0
Utilization
2%
Speed
1.20 GHz
Processes
156
Threads
1938
Handles
70690
Up time
13:02:46:34
Base speed: 2.60 GHz
Sockets: 1
Cores: 2
Logical processors: 4
Virtualization: Enabled
L1 cache: 128 KB
L2 cache: 512 KB
L3 cache: 3.0 MB
Fewer details
Open Resource Monitor

```
PS D:\poland\VS-projects\PORR\CRS\x64\Release> .\CRS.exe 10

Initialization time = 0.019913

********** SOLUTION **********
Execution time = 0.134021
x=[-0.002391,-0.007413,-0.009085,-0.013841,-0.010932,-0.011114,0.030373,0.068612,-0.037999,-0.038401
]
Number of evaluations: 39118
Min value = 0.000315041
Max value = 0.00131328
PS D:\poland\VS-projects\PORR\CRS\x64\Release>
```

```
PS D:\poland\VS-projects\PORR\CRS\x64\Release> .\CRS_omp3.exe 10

Initialization time = 0.0098239

********** SOLUTION **********
Execution time = 0.172214
x=[-0.001101,-0.018947,-0.040566,-0.004475,0.011314,-0.027518,0.035273,-0.013590,0.022219,-0.037924]

Number of evaluations: 32758
Min value = 0.000331771
Max value = 0.0013219
PS D:\poland\VS-projects\PORR\CRS\x64\Release>
```

```
PS D:\poland\VS-projects\PORR\CRS\x64\Release> .\CRS.exe 50

Initialization time = 0.32744

********** SOLUTION **********
Execution time = 4.06096
x=[-0.001470,0.002024,-0.003429,0.008992,-0.042395,0.098690,0.026983,-0.017516,-0.029722,0.085520,-0
.153302,-0.148622,0.127410,-0.163628,0.062269,-0.016392,0.168594,0.036868,-0.139154,-0.090601,-0.117
059,0.015437,-0.070109,-0.083494,0.100344,-0.118512,-0.144061,-0.010173,-0.095962,-0.090291,-0.14032
2,-0.096749,-0.025682,-0.011288,0.008548,-0.072786,-0.002498,-0.150900,-0.069066,-0.070184,-0.118065
,0.054938,-0.015072,-0.118669,0.185646,-0.081227,-0.058357,0.066052,-0.039432,0.013911]
Number of evaluations: 222777
Min value = 0.0109499
Max value = 0.0119497
```

```
PS D:\poland\VS-projects\PORR\CRS\x64\Release> .\CRS_omp3.exe 50

Initialization time = 0.130321

********** SOLUTION **********
Execution time = 3.10717
x=[0.068229,-0.150064,0.045476,0.003404,0.420478,0.140239,-0.390290,-0.003885,0.340255,0.152727,-0.2
77147,-0.226386,0.560067,0.355780,-0.247614,0.057422,0.119692,0.294384,0.251467,0.225659,0.178143,-0
.453763,0.172346,-0.249315,0.652280,0.344537,0.106278,0.096816,0.103396,-0.251413,0.026240,0.330472,
0.115597,-0.188079,0.334420,0.314068,0.421237,-0.095921,0.199280,-0.038906,-0.124466,0.358144,-0.442
725,-0.093798,-0.304895,-0.677860,-0.255889,-0.398225,0.227319,0.280353]
Number of evaluations: 162542
Min value = 0.119552
Max value = 0.120552
```

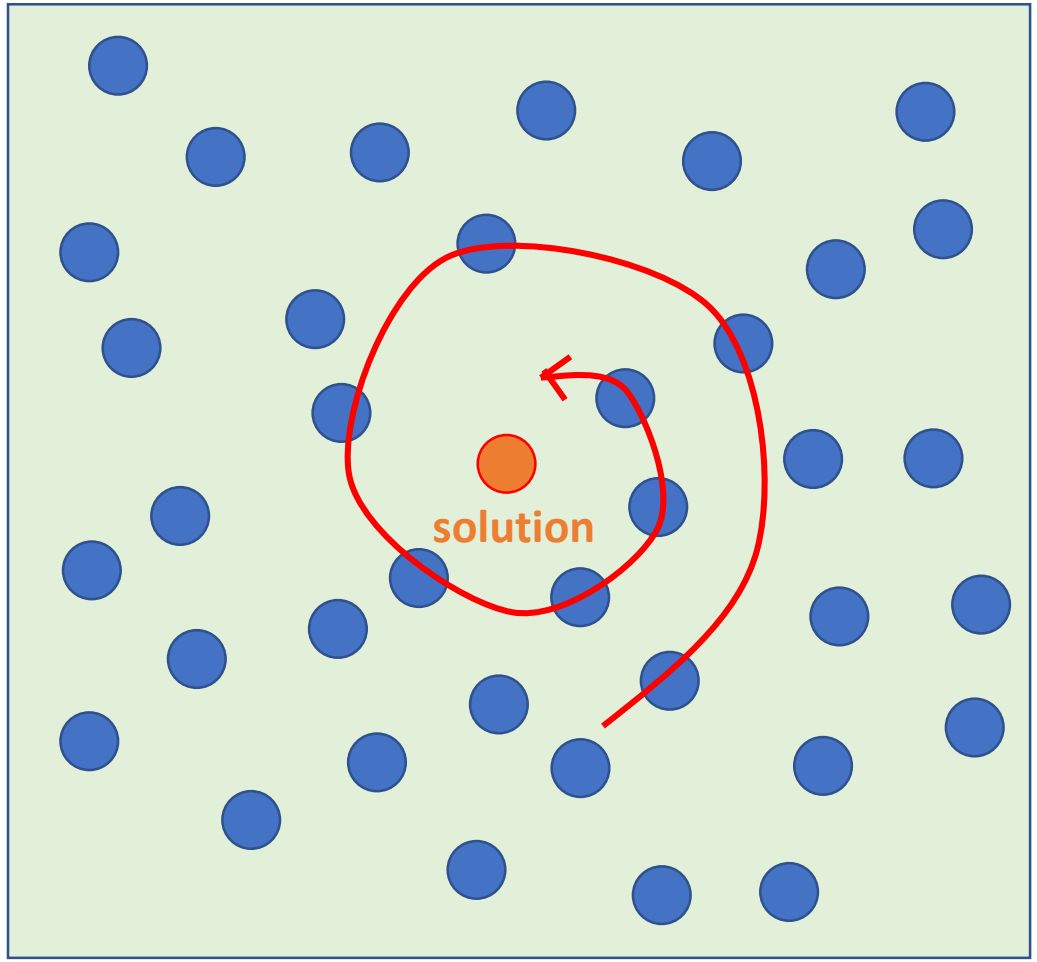
```
PS D:\poland\VS-projects\PORR\CRS\x64\Release> .\CRS.exe 100

Initialization time = 1.36324

************** SOLUTION ********************
Execution time = 31.606
x=[-0.011254,-0.088317,0.037274,0.059691,-0.159390,-0.060184,0.182447,-0.070534,0.167143,-0.048542,0
.406162,-0.022379,0.112367,0.042080,0.071111,0.296803,-0.152758,0.039102,-0.120451,0.077645,-0.23565
3,-0.021900,0.029014,0.009119,-0.234839,-0.057858,0.036125,-0.201100,-0.107198,-0.024862,-0.082618,0
.021591,-0.301452,0.179651,-0.130994,-0.002202,-0.011334,-0.046666,-0.008861,-0.145916,-0.271443,0.1
26260,0.086927,0.189520,0.018637,0.041207,-0.184099,-0.091410,-0.130153,0.022034,-0.137519,-0.187129
,-0.198991,0.026884,-0.029378,-0.226177,0.090362,0.141170,-0.059760,0.106672,-0.199553,-0.025666,-0.
035505,-0.259747,-0.206096,0.345604,-0.078199,0.059800,0.045960,0.121892,0.009993,0.117858,0.105085,
0.051317,0.084871,-0.177080,-0.284498,-0.124020,-0.117604,0.141808,-0.211249,0.089729,0.121793,-0.16
6070,0.003838,-0.050353,0.016728,0.050334,0.074205,-0.139928,0.291487,-0.299340,0.140030,0.087670,0.
170006,-0.051960,0.062781,0.041257,0.024673,0.147964]
Number of evaluations: 422095
Min value = 0.0545739
Max value = 0.0555738
```

```
PS D:\poland\VS-projects\PORR\CRS\x64\Release> .\CRS_omp3.exe 100

Initialization time = 0.489864

************** SOLUTION ********************
Execution time = 13.2778
x=[-0.049110,0.004306,0.033029,0.364912,-0.357897,0.161467,-0.301015,-0.104250,-0.318701,-0.156668,-
0.193168,0.114274,-0.287965,-0.435096,-0.024732,0.227695,-0.180241,-0.248948,0.060334,0.108107,0.552
211,-0.371046,-0.052799,0.365695,0.766100,-0.388192,-0.240518,-0.139892,-0.452635,0.002133,0.211577,
0.057784,0.356562,0.579511,-0.095390,0.374144,-0.031256,0.356328,0.015802,-0.105515,-0.346911,0.4316
18,0.235321,0.507554,0.086694,0.108949,-0.455376,0.253036,-0.455672,0.143974,-0.058658,0.362508,0.20
3647,-0.191012,-0.015782,0.394777,0.002073,-0.053402,0.593675,0.231904,-0.347889,0.237795,-0.104241,
0.044889,-0.196793,-0.265264,-0.231765,0.044479,-0.082349,0.082574,-0.335992,-0.281909,-0.065028,-0.
097539,-0.140070,-0.474954,0.843248,-0.012279,0.305481,0.266332,0.364755,-0.303264,-0.562511,0.53433
6,-0.073928,-0.021781,0.395291,-0.159015,0.212645,0.184091,0.436275,-0.319702,-0.046873,-0.496384,0.
085946,-0.232394,0.078745,-0.434659,-0.030551,-0.024724]
Number of evaluations: 306498
Min value = 0.236288
Max value = 0.237287
```

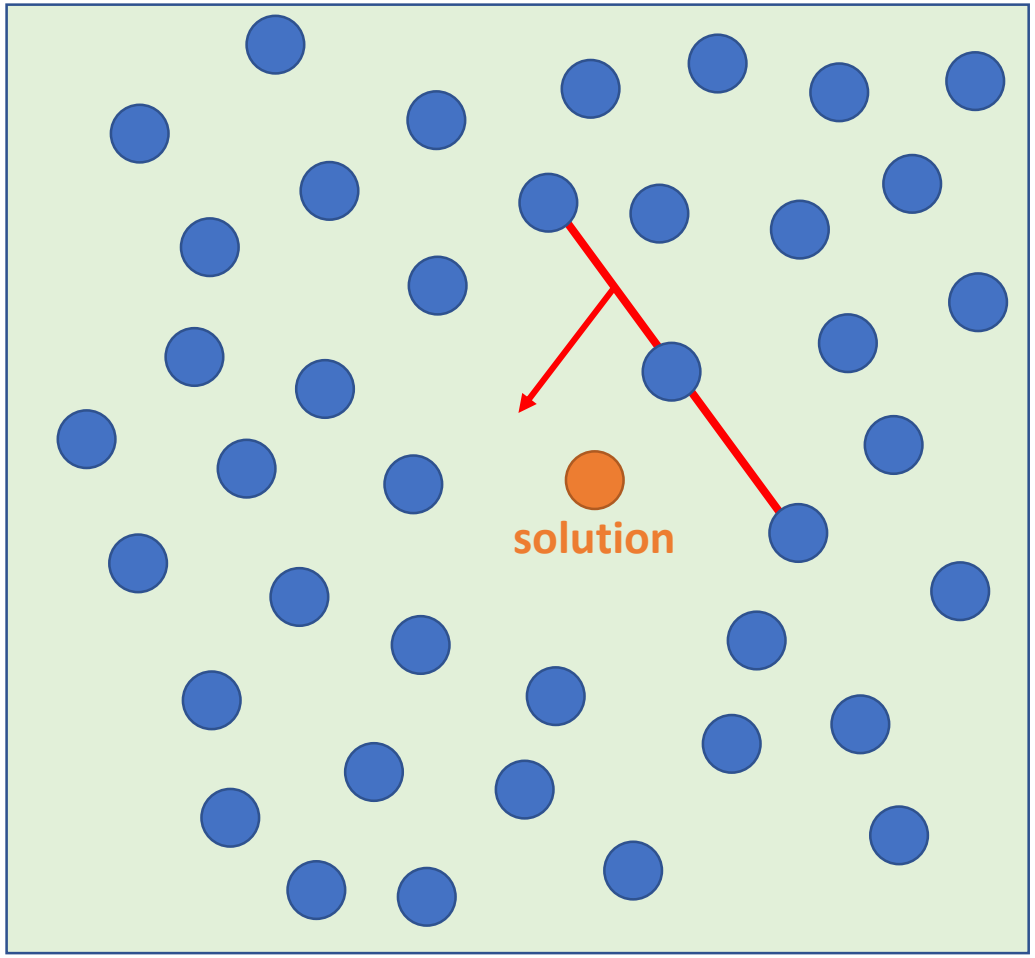
The reason I get solutions is that there's a significant difference between a parallel version and a sequential version:

- In the sequential version, each new solution point is calculated after all the new solution points of the previous iterations updated.
- While in the parallel version, no_threads times of new solution points will be calculated based on the same version population updated by the previous loop.
- Somehow, intuitively, I can imagine in the sequential version, the convergence **might be sharper** than the parallel version.

Convergence process intuitively



Convergence process of sequential version



Convergence process of parallel version