transfer

May 1, 2022

[ ]:
```
## according to cpuworld opteron 6272 is bulldozer cpu with '16' cores. That␣
 ↪means only 8 fpu's and 16 alus represented as 16 cores.
## And the task use fpu. L2 cache is 'shared' per 2 ALU 1 FPU (1 block). L3 is␣
 ↪shared. According to cpuworld 2x8mB L3 points to NUMA
## 4 + 4 blocks. The task uses memory much more than calculation (~1024M for␣
 ↪64bit double). So optimal perf is predicted at 4 threads.
## And yes there is definite dip there.

import numpy as np
import subprocess
from mpl_toolkits import mplot3d
%matplotlib widget
import matplotlib.pyplot as plt
plt.style.use('dark_background')
from tabulate import tabulate
from tqdm import tqdm
```

[ ]:
```
x_max = 5
t_max = 10
# 3d surface work properly only when x_points == t_points
x_points = 512
t_points = 512
n_proc = 6

plt_rcount = 128
plt_ccount = 128

t_points_at_x_var = 100
x_points_start = n_proc
x_points_end = 25000
x_var_step = 1000

x_points_at_t_var = 100
t_points_start = 10
t_points_end = 25000
t_var_step = 1000
```

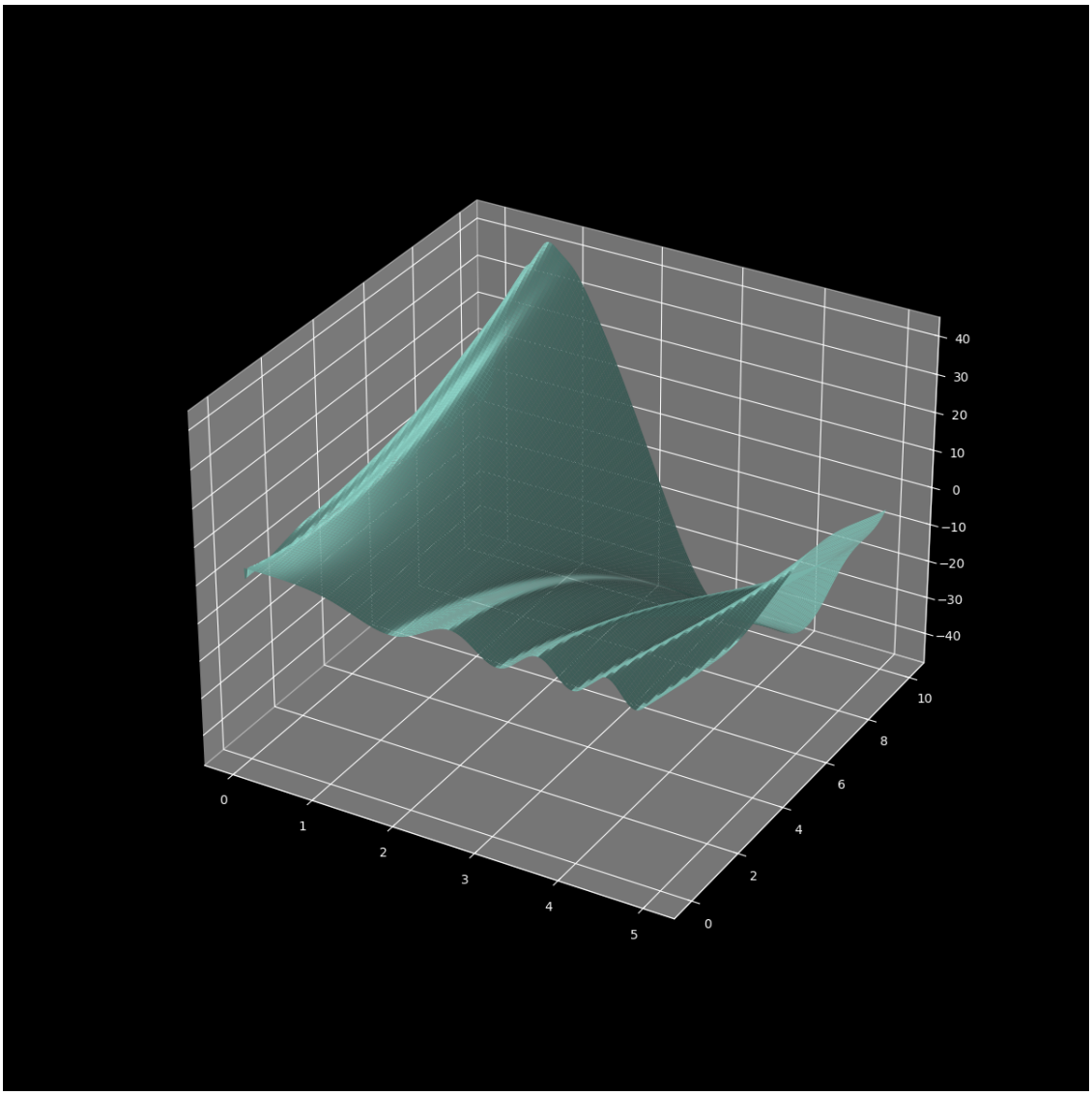
```
np_start = 1
np_end = 6
t_points_at_np_var = 4096
x_points_at_np_var = 4096
```

[ ]:
```
matrix = np.zeros ((x_points, x_points))
perf_ranks = np.zeros ((n_proc, 3))
result = subprocess.run (["mpirun", "-np", "{0}".format (n_proc), "./transfer",␣
 ↪"{0}".format (x_points), "{0}".format (t_points), "{0}".format (x_max),␣
 ↪"{0}".format (t_max), "{0}".format (t_points - x_points), "{0}".format␣
 ↪(t_points)], capture_output=True, text=True)
res_split = result.stdout.split ()
for i in range (0, x_points):
    for j in range (0, x_points):
        matrix[i][j] = res_split[i * x_points + j]
for i in range (0, n_proc):
    rank = res_split[x_points * x_points + i * 4]
    for j in range (0, 3):
        perf_ranks[int (rank)][j] = res_split[x_points * x_points + i * 4 + j +␣
 ↪1]
#print ("last layer :")
#print (matrix[x_points - 1])

tabledata = []
for i in range (0, n_proc):
    temp = []
    temp.append (i)
    temp.append (perf_ranks[i][0])
    temp.append (perf_ranks[i][1])
    temp.append (perf_ranks[i][2])
    tabledata.append (temp)
print (tabulate (tabledata, headers = ["rank", "calc time", "gather time",␣
 ↪"total time"]))

X = np.outer (np.linspace (0, x_max, x_points), np.ones (x_points)).copy().T
T = np.outer (np.linspace (0, t_max, x_points), np.ones (x_points))
plt.figure(figsize=(12, 12))
plt.axes(projection ='3d').plot_surface (X, T, matrix, rcount = plt_rcount,␣
 ↪ccount = plt_ccount)
```

```
  rank    calc time    gather time    total time
------  -----------  -------------  ------------
     0   0.00270382     0.00224559    0.0814336
     1   0.00270986     0.00106214    0.00377561
     2   0.00273844     0.00135397    0.00441356
     3   0.00274905     0.0016526     0.00440943
     4   0.00275204     0.00188906    0.00485712
```

```
5    0.00274619      0.00210266      0.00485308
```

[ ]:
```
<mpl_toolkits.mplot3d.art3d.Poly3DCollection at 0x7fad717ddb10>
```



[ ]:
```
### x_points var at host
x_points_var = np.zeros (int ((x_points_end - x_points_start) / x_var_step) + 1)
times = np.zeros ((3, n_proc, int ((x_points_end - x_points_start) /␣
 ↪x_var_step) + 1))
i = x_points_start
k = 0
tabledata = []
with tqdm(total=int ((x_points_end - x_points_start) / x_var_step) + 1) as pbar:
    while i < x_points_end:
```

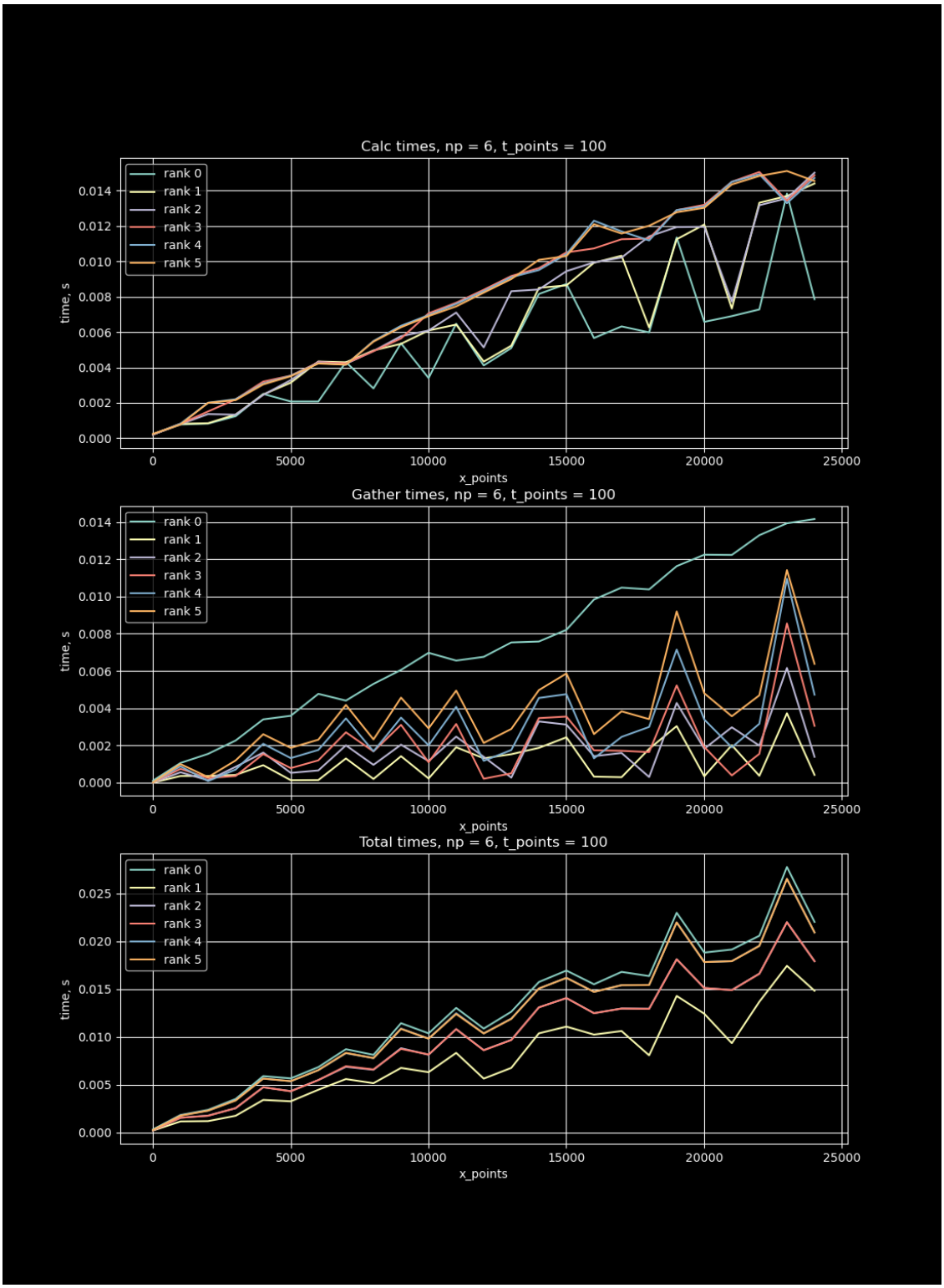
```
        result = subprocess.run (["mpirun", "-np", "{0}".format (n_proc), "./
 ↪transfer", "{0}".format (i), "{0}".format (t_points_at_x_var), "{0}".format␣
 ↪(x_max), "{0}".format (t_max), "n"], capture_output=True, text=True)
        res_split = result.stdout.split ()
        times_max = np.zeros (3)
        for p in range (0, n_proc):
            rank = int (res_split[p * 4])
            for j in range (0, 3):
                times[j][rank][k] = res_split[p * 4 + j + 1]
                if times[j][rank][k] > times_max[j]:
                    times_max[j] = times[j][rank][k]
        x_points_var[k] = i
        temp = []
        temp.append (i)
        temp.append (times_max[0])
        temp.append (times_max[1])
        temp.append (times_max[2])
        tabledata.append (temp)
        i = i + x_var_step
        k = k + 1
        pbar.update (1)

print (tabulate (tabledata, headers = ["x_points", "max calc time", "max gather␣
 ↪time", "max total time"]))

plt.figure (figsize = [11, 15])

plt.subplot (311)
plt.grid ()
plt.title ("Calc times, np = {0}, t_points = {1}".format(n_proc,␣
 ↪t_points_at_x_var))
plt.xlabel ("x_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (x_points_var, times[0][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()

plt.subplot (312)
plt.grid ()
plt.title ("Gather times, np = {0}, t_points = {1}".format(n_proc,␣
 ↪t_points_at_x_var))
plt.xlabel ("x_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (x_points_var, times[1][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
```

```
plt.legend ()

plt.subplot (313)
plt.grid ()
plt.title ("Total times, np = {0}, t_points = {1}".format(n_proc,␣
 ↪t_points_at_x_var))
plt.xlabel ("x_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (x_points_var, times[2][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()
```

```
100%|
                                  | 25/25
[00:02<00:00,  8.63it/s]
```

x_points	max calc time	max gather time	max total time
6	0.000244114	0.000106001	0.000334588
1006	0.000816147	0.00105934	0.00184412
2006	0.00200621	0.00154811	0.00238091
3006	0.0022055	0.00226461	0.00351707
4006	0.00319828	0.00339944	0.00591257
5006	0.00353381	0.00359318	0.0056731
6006	0.00433612	0.00476969	0.00684968
7006	0.00430538	0.00440623	0.00872175
8006	0.00549531	0.00530391	0.00812626
9006	0.00635621	0.00605759	0.0114392
10006	0.00706187	0.00697288	0.0103813
11006	0.00765814	0.00655525	0.0130409
12006	0.00839243	0.00675654	0.0108759
13006	0.00917199	0.00753044	0.0126384
14006	0.0100831	0.00757966	0.0157441
15006	0.0105033	0.00821043	0.0169461
16006	0.0122977	0.00983492	0.0155101
17006	0.0116954	0.010475	0.0168048
18006	0.0120125	0.0103776	0.0163664
19006	0.0129002	0.0116264	0.0229908
20006	0.0131976	0.0122427	0.0188285
21006	0.0145001	0.0122295	0.019144
22006	0.0150532	0.013288	0.0205827
23006	0.0151085	0.0139281	0.027773
24006	0.0150132	0.0141584	0.0220257

[ ]: <matplotlib.legend.Legend at 0x7fad65db6c20>


Calc times, np = 6, t_points = 100
rank 0
rank 1
rank 2
rank 3
rank 4
rank 5
time, s
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0
5000
10000
15000
20000
25000
x_points
Gather times, np = 6, t_points = 100
rank 0
rank 1
rank 2
rank 3
rank 4
rank 5
time, s
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0
5000
10000
15000
20000
25000
x_points
Total times, np = 6, t_points = 100
rank 0
rank 1
rank 2
rank 3
rank 4
rank 5
time, s
0.000
0.005
0.010
0.015
0.020
0.025
0
5000
10000
15000
20000
25000
x_points

[ ]:
```
### t_points var at host
t_points_var = np.zeros (int ((t_points_end - t_points_start) / t_var_step) + 1)
times = np.zeros ((3, n_proc, int ((t_points_end - t_points_start) /␣
 ↪t_var_step) + 1))
i = t_points_start
k = 0
tabledata = []
with tqdm (total = int ((t_points_end - t_points_start) / t_var_step) + 1) as␣
 ↪pbar:
    while i < t_points_end:
        result = subprocess.run (["mpirun", "-np", "{0}".format (n_proc), "./
 ↪transfer", "{0}".format (x_points_at_t_var), "{0}".format (i), "{0}".format␣
 ↪(x_max), "{0}".format (t_max), "n"], capture_output=True, text=True)
        res_split = result.stdout.split ()
        times_max = np.zeros (3)
        for p in range (0, n_proc):
            rank = int (res_split[p * 4])
            for j in range (0, 3):
                times[j][rank][k] = res_split[p * 4 + j + 1]
                if times[j][rank][k] > times_max[j]:
                    times_max[j] = times[j][rank][k]
        t_points_var[k] = i
        temp = []
        temp.append (i)
        temp.append (times_max[0])
        temp.append (times_max[1])
        temp.append (times_max[2])
        tabledata.append (temp)
        i = i + t_var_step
        k = k + 1
        pbar.update (1)

print (tabulate (tabledata, headers = ["t_points", "max calc time", "max gather␣
 ↪time", "max total time"]))

plt.figure (figsize = [11, 15])

plt.subplot (311)
plt.grid ()
plt.title ("Calc times, np = {0}, x_points = {1}".format(n_proc,␣
 ↪x_points_at_t_var))
plt.xlabel ("t_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (t_points_var, times[0][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()
```

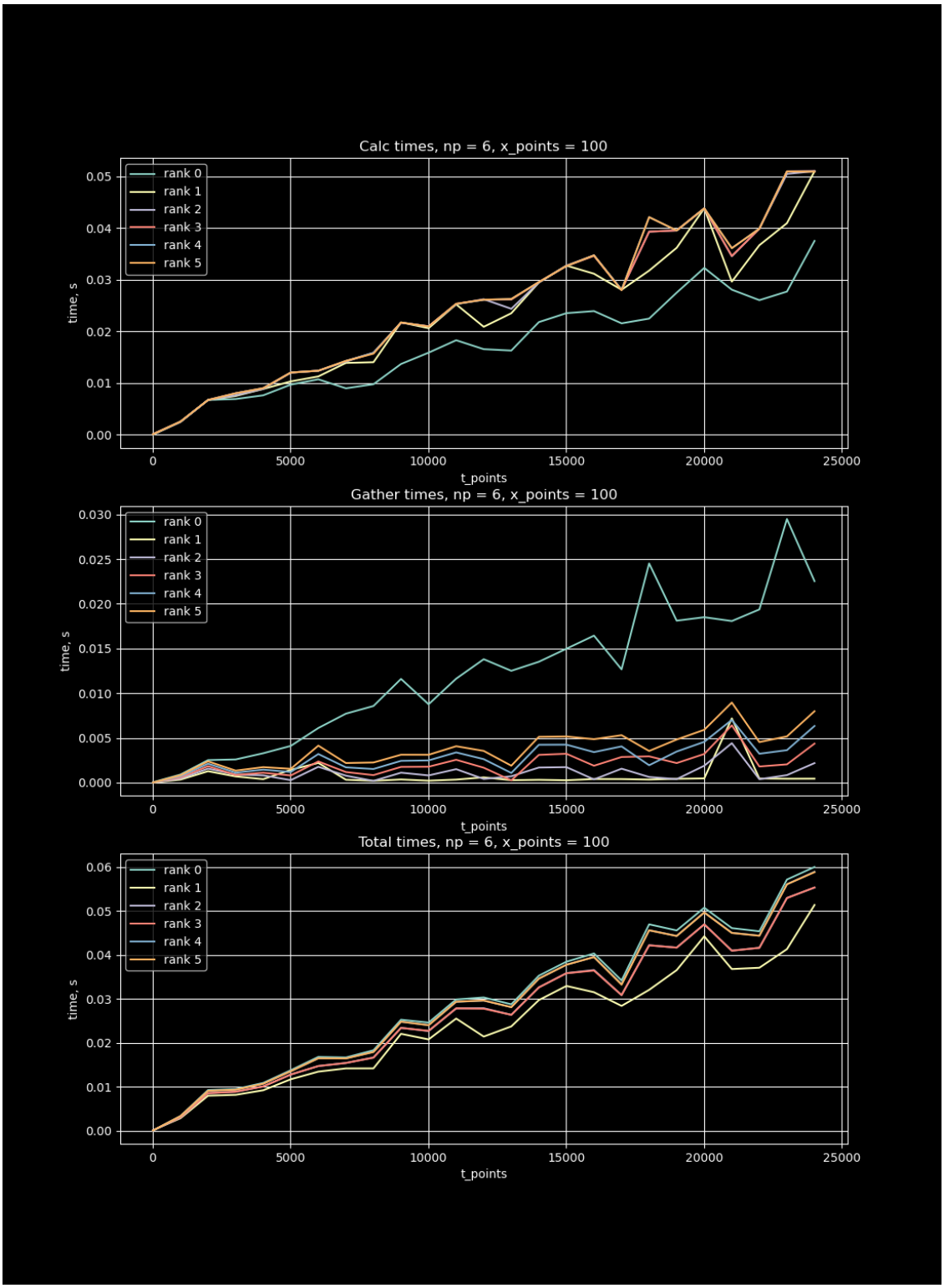
```
plt.subplot (312)
plt.grid ()
plt.title ("Gather times, np = {0}, x_points = {1}".format(n_proc,␣
 ↪x_points_at_t_var))
plt.xlabel ("t_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (t_points_var, times[1][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()

plt.subplot (313)
plt.grid ()
plt.title ("Total times, np = {0}, x_points = {1}".format(n_proc,␣
 ↪x_points_at_t_var))
plt.xlabel ("t_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (t_points_var, times[2][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()
```

```
100%|      | 25/25 [00:04<00:00,  6.25it/s]
```

t_points	max calc time	max gather time	max total time
10	0.000142526	4.583e-05	0.0001522
1010	0.0025634	0.000908808	0.00339882
2010	0.00674358	0.00252149	0.00931163
3010	0.00804766	0.00259447	0.00952815
4010	0.00901695	0.0032868	0.0109356
5010	0.0120374	0.00410775	0.0138246
6010	0.0123891	0.00610824	0.016852
7010	0.0142904	0.00771374	0.0167215
8010	0.0158604	0.00856952	0.0183662
9010	0.0217322	0.0115995	0.0253081
10010	0.0209985	0.00876315	0.0246609
11010	0.0253299	0.0116244	0.0299182
12010	0.0262179	0.0138012	0.0303763
13010	0.0262601	0.012505	0.0288082
14010	0.0295355	0.0135161	0.0353259
15010	0.032714	0.0149729	0.0385087
16010	0.0346979	0.0164389	0.040379
17010	0.0280667	0.0126655	0.034236
18010	0.0420841	0.0245095	0.0470024
19010	0.039507	0.0181076	0.045606
20010	0.0437828	0.0184984	0.0507843

```
21010      0.0360941          0.0180661          0.046141
22010      0.0398666          0.0193666          0.0454117
23010      0.0509216          0.0294784          0.0571884
24010      0.051              0.0225274          0.0600409
```

[ ]: <matplotlib.legend.Legend at 0x7f38f6b590f0>


Calc times, np = 6, x_points = 100
rank 0
rank 1
rank 2
rank 3
rank 4
rank 5
time, s
t_points
Gather times, np = 6, x_points = 100
rank 0
rank 1
rank 2
rank 3
rank 4
rank 5
time, s
t_points
Total times, np = 6, x_points = 100
rank 0
rank 1
rank 2
rank 3
rank 4
rank 5
time, s
t_points

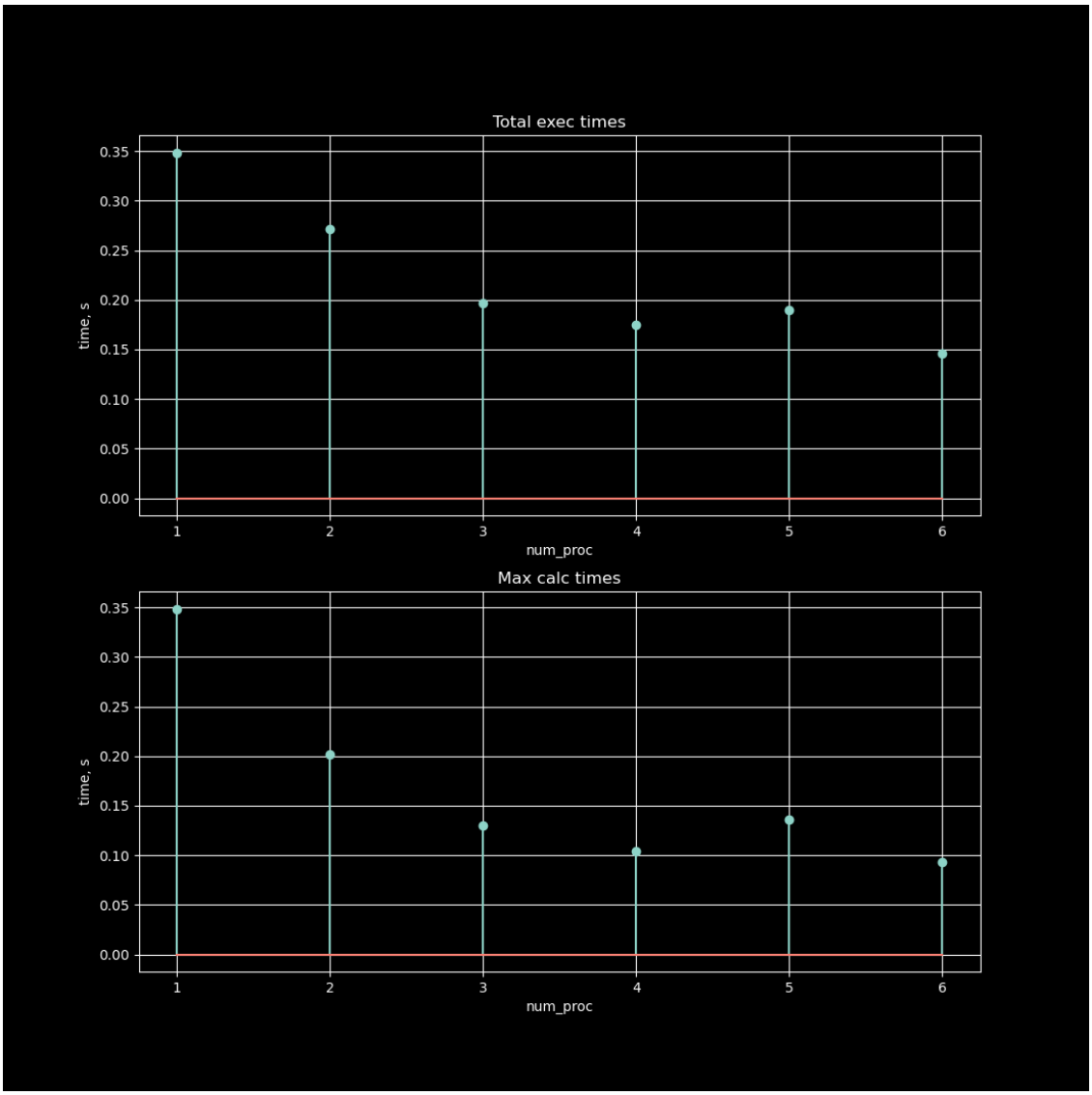
[ ]:
```
### np var at host

np_var = np.arange (np_start, np_end + 1)
times = np.zeros ((3, np_end - np_start + 1))
i = np_start
tabledata = []
with tqdm (total = np_end - np_start + 1) as pbar:
    while i <= np_end:
        result = subprocess.run (["mpirun", "-np", "{0}".format (i), "./
 ↪transfer", "{0}".format (x_points_at_np_var), "{0}".format␣
 ↪(t_points_at_np_var), "{0}".format (x_max), "{0}".format (t_max), "n"],␣
 ↪capture_output=True, text=True)
        res_split = result.stdout.split ()
        max_calc = 0
        max_gather = 0
        max_total = 0
        for p in range (0, i - np_start + 1):
            if float (res_split[p * 4 + 1]) > max_calc:
                max_calc = float (res_split[p * 4 + 1])
            if float (res_split[p * 4 + 2]) > max_gather:
                max_gather = float (res_split[p * 4 + 2])
            if float (res_split[p * 4 + 3]) > max_total:
                max_total = float (res_split[p * 4 + 3])

        times[0][i - np_start] = max_calc
        times[1][i - np_start] = max_gather
        times[2][i - np_start] = max_total
        temp = []
        temp.append (i)
        temp.append (max_calc)
        temp.append (max_gather)
        temp.append (max_total)
        tabledata.append (temp)
        i = i + 1
        pbar.update (1)

print (tabulate (tabledata, headers = ["N proc", "max calc time", "max gather␣
 ↪time", "max total time"]))

plt.figure (figsize = [11, 11])

plt.subplot (211)
plt.grid ()
plt.title ("Total exec times")
plt.xlabel ("num_proc")
plt.ylabel ("time, s")
plt.stem (np_var, times[2])
```

```
plt.subplot (212)
plt.grid ()
plt.title ("Max calc times")
plt.xlabel ("num_proc")
plt.ylabel ("time, s")
plt.stem (np_var, times[0])
```

```
100%|                                   | 6/6
[00:02<00:00,  2.97it/s]
```

N proc	max calc time	max gather time	max total time
1	0.348612	3.3e-08	0.348645
2	0.201602	0.0958639	0.270976
3	0.13007	0.0912261	0.196746
4	0.104455	0.0930524	0.174533
5	0.135799	0.120016	0.190254
6	0.0932826	0.0910135	0.145735

[ ]: <StemContainer object of 3 artists>



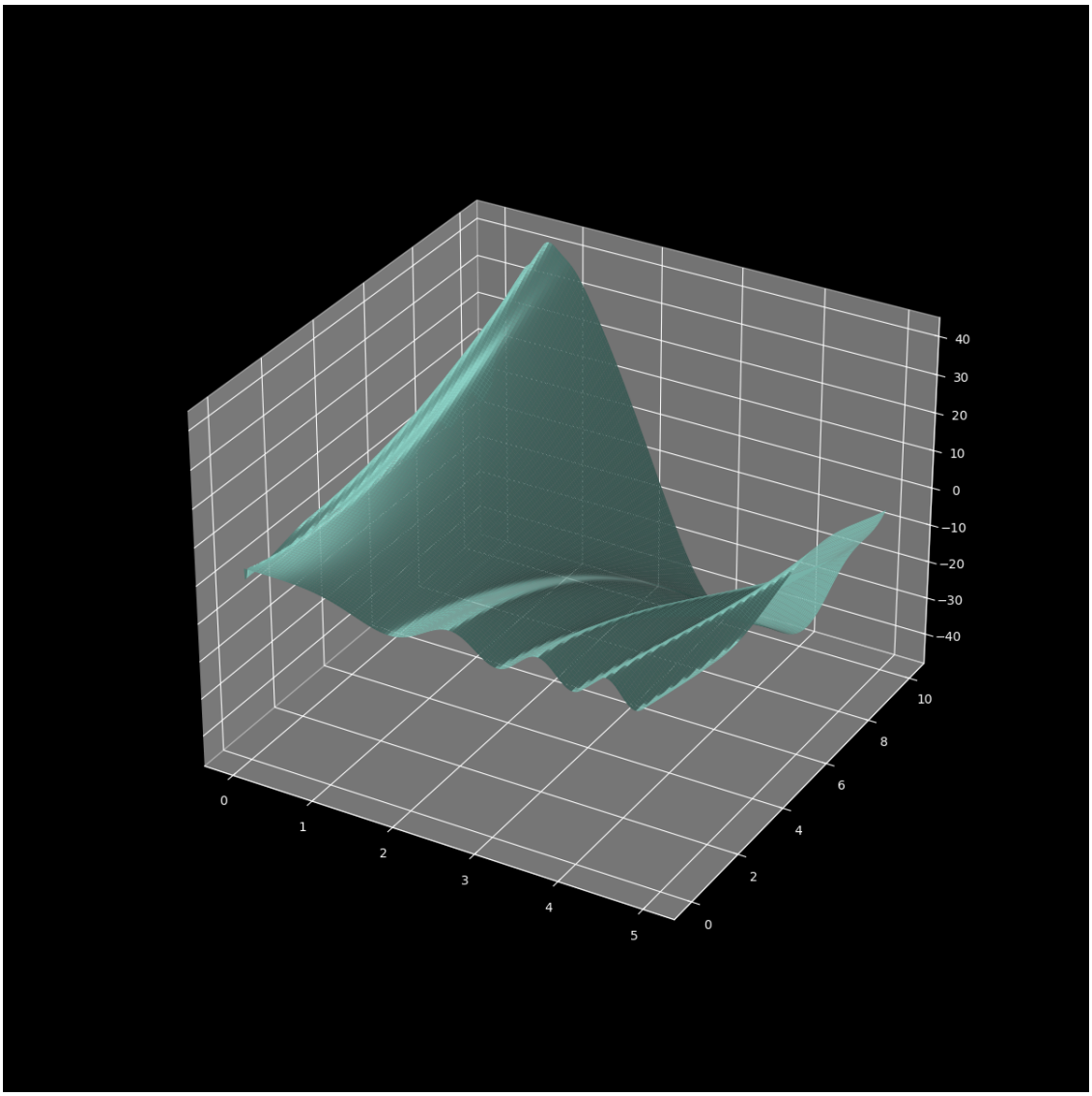
[ ]:
```
#### CLUSTER through ssh ####
import time
n_proc = 4
np_start = 1
np_end = 32

matrix = np.zeros ((x_points, x_points))
perf_ranks = np.zeros ((n_proc, 3))
compile = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "NUM_PROC={0}".format (n_proc), "ARGS=\"", "{0}".format (x_points),␣
 ↪"{0}".format (t_points), "{0}".format (x_max), "{0}".format (t_max), "{0}".
 ↪format (t_points - x_points), "{0}\"".format (t_points) , "-C", "./lab1/"])
```

```
#print (compile)
time.sleep (2)
run = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "-C", "./lab1/", "run"])
time.sleep (2)
result = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"cat", "./lab1/stdout.txt"], capture_output=True, text=True)
res_split = result.stdout.split ()
for i in range (0, x_points):
    for j in range (0, x_points):
        matrix[i][j] = res_split[i * x_points + j]
for i in range (0, n_proc):
    rank = res_split[x_points * x_points + i * 4]
    for j in range (0, 3):
        perf_ranks[int (rank)][j] = res_split[x_points * x_points + i * 4 + j +␣
 ↪1]
#print ("last layer :")
#print (matrix[x_points - 1])

tabledata = []
for i in range (0, n_proc):
    temp = []
    temp.append (i)
    temp.append (perf_ranks[i][0])
    temp.append (perf_ranks[i][1])
    temp.append (perf_ranks[i][2])
    tabledata.append (temp)
print (tabulate (tabledata, headers = ["rank", "calc time", "gather time",␣
 ↪"total time"]))

X = np.outer (np.linspace (0, x_max, x_points), np.ones (x_points)).copy().T
T = np.outer (np.linspace (0, t_max, x_points), np.ones (x_points))
plt.figure(figsize=(12, 12))
plt.axes(projection ='3d').plot_surface (X, T, matrix, rcount = plt_rcount,␣
 ↪ccount = plt_ccount)
```

```
make: Entering directory `/home/b0190302/lab1'
mpic++ "-std=c++11"  -o Lab1  main.cpp
echo -e "\043PBS -l "walltime=00:01:00" \n\043PBS -N Lab1 \n\043PBS -q batch
\ncd \044PBS_O_WORKDIR \nmpirun --hostfile \044PBS_NODEFILE "-np 4"  ./Lab1 512
512 5 10 0 512"    > job.sh
make: Leaving directory `/home/b0190302/lab1'
make: Entering directory `/home/b0190302/lab1'
qsub -o stdout.txt ./job.sh
152889.head.vdi.mipt.ru
```

```
make: Leaving directory `/home/b0190302/lab1'
  rank    calc time    gather time    total time
------  -----------  -------------  ------------
     0   0.00712609     0.0054729      0.311475
     1   0.00890279     0.001194       0.0101192
     2   0.00946307     0.00123715     0.01072
     3   0.00944901     0.00222993     0.0116942
```

[ ]: <mpl_toolkits.mplot3d.art3d.Poly3DCollection at 0x7f38fd786290>



[ ]:
```
### x_points var at cluster

x_points_var = np.zeros (int ((x_points_end - x_points_start) / x_var_step) + 1)
```

```
times = np.zeros ((3, n_proc, int ((x_points_end - x_points_start) /␣
 ↪x_var_step) + 1))
i = x_points_start
k = 0
tabledata = []
with tqdm(total=int ((x_points_end - x_points_start) / x_var_step) + 1) as pbar:
    while i < x_points_end:
        compile = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "NUM_PROC={0}".format (n_proc), "ARGS=\"", "{0}".format (i), "{0}".
 ↪format (t_points_at_x_var), "{0}".format (x_max), "{0}".format (t_max),␣
 ↪"n\"", "-C", "./lab1/"], capture_output=True)
        time.sleep (2)
        #print (compile)
        run = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "-C", "./lab1/", "run"], capture_output=True)
        time.sleep (2)
        result = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"cat", "./lab1/stdout.txt"], capture_output=True, text=True)
        #print (result)
        res_split = result.stdout.split ()
        times_max = np.zeros (3)
        for p in range (0, n_proc):
            rank = int (res_split[p * 4])
            for j in range (0, 3):
                times[j][rank][k] = res_split[p * 4 + j + 1]
                if times[j][rank][k] > times_max[j]:
                    times_max[j] = times[j][rank][k]
        x_points_var[k] = i
        temp = []
        temp.append (i)
        temp.append (times_max[0])
        temp.append (times_max[1])
        temp.append (times_max[2])
        tabledata.append (temp)
        i = i + x_var_step
        k = k + 1
        pbar.update (1)

print (tabulate (tabledata, headers = ["x_points", "max calc time", "max gather␣
 ↪time", "max total time"]))

plt.figure (figsize = [11, 15])

plt.subplot (311)
```

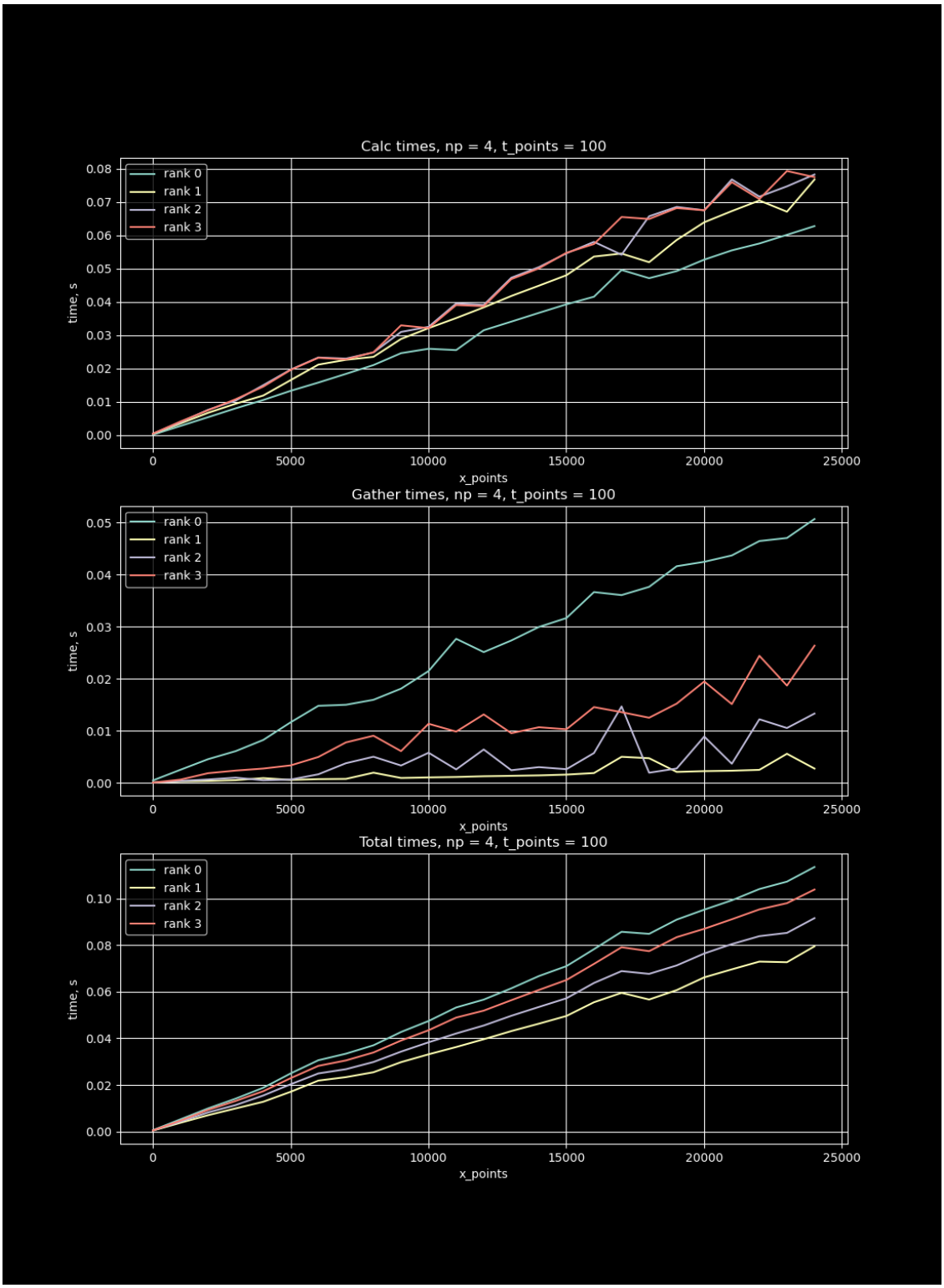
```
plt.grid ()
plt.title ("Calc times, np = {0}, t_points = {1}".format(n_proc,␣
 ↪t_points_at_x_var))
plt.xlabel ("x_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (x_points_var, times[0][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()

plt.subplot (312)
plt.grid ()
plt.title ("Gather times, np = {0}, t_points = {1}".format(n_proc,␣
 ↪t_points_at_x_var))
plt.xlabel ("x_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (x_points_var, times[1][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()

plt.subplot (313)
plt.grid ()
plt.title ("Total times, np = {0}, t_points = {1}".format(n_proc,␣
 ↪t_points_at_x_var))
plt.xlabel ("x_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (x_points_var, times[2][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()
```

```
100%|      | 25/25 [02:42<00:00,  6.52s/it]
```

x_points	max calc time	max gather time	max total time
6	0.000479221	0.000447035	0.000646114
1006	0.00412416	0.0024941	0.00531101
2006	0.00762391	0.00452805	0.00997806
3006	0.0108049	0.00606918	0.014158
4006	0.015008	0.00821209	0.018816
5006	0.0197029	0.0116248	0.0249991
6006	0.0233331	0.0147781	0.0306208
7006	0.02299	0.014976	0.0334241
8006	0.0248959	0.0159321	0.0370381
9006	0.032975	0.01807	0.0427339
10006	0.032531	0.021462	0.0474539

11006	0.03952	0.0276549	0.0532491
12006	0.0390968	0.02509	0.0566289
13006	0.0472541	0.0273299	0.0614638
14006	0.0504301	0.0299249	0.066705
15006	0.0547318	0.0316389	0.0709741
16006	0.0580201	0.0366309	0.0782518
17006	0.0654809	0.0360529	0.085691
18006	0.0656991	0.0376322	0.084805
19006	0.068511	0.0415969	0.0909181
20006	0.067497	0.0424471	0.095192
21006	0.0767519	0.0436699	0.099189
22006	0.071594	0.046432	0.104026
23006	0.079278	0.0470181	0.107218
24006	0.0782301	0.050668	0.113483

[ ]: <matplotlib.legend.Legend at 0x7f38f6337ee0>


Calc times, np = 4, t_points = 100
rank 0
rank 1
rank 2
rank 3
time, s
x_points
Gather times, np = 4, t_points = 100
rank 0
rank 1
rank 2
rank 3
time, s
x_points
Total times, np = 4, t_points = 100
rank 0
rank 1
rank 2
rank 3
time, s
x_points

```
[ ]: ### t_points var at cluster

t_points_var = np.zeros (int ((t_points_end - t_points_start) / t_var_step) + 1)
times = np.zeros ((3, n_proc, int ((t_points_end - t_points_start) /␣
 ↪t_var_step) + 1))
i = t_points_start
k = 0
tabledata = []
with tqdm(total=int ((t_points_end - t_points_start) / t_var_step) + 1) as pbar:
    while i < t_points_end:
        compile = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "NUM_PROC={0}".format (n_proc), "ARGS=\"", "{0}".format␣
 ↪(x_points_at_t_var), "{0}".format (i), "{0}".format (x_max), "{0}".format␣
 ↪(t_max), "n\"", "-C", "./lab1/"], capture_output=True)
        time.sleep (2)
        run = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "-C", "./lab1/", "run"], capture_output=True)
        time.sleep (2)
        result = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"cat", "./lab1/stdout.txt"], capture_output=True, text=True)
        res_split = result.stdout.split ()
        times_max = np.zeros (3)
        for p in range (0, n_proc):
            rank = int (res_split[p * 4])
            for j in range (0, 3):
                times[j][rank][k] = res_split[p * 4 + j + 1]
                if times[j][rank][k] > times_max[j]:
                    times_max[j] = times[j][rank][k]
        t_points_var[k] = i
        temp = []
        temp.append (i)
        temp.append (times_max[0])
        temp.append (times_max[1])
        temp.append (times_max[2])
        tabledata.append (temp)
        i = i + t_var_step
        k = k + 1
        pbar.update (1)

print (tabulate (tabledata, headers = ["t_points", "max calc time", "max gather␣
 ↪time", "max total time"]))

plt.figure (figsize = [11, 15])
```

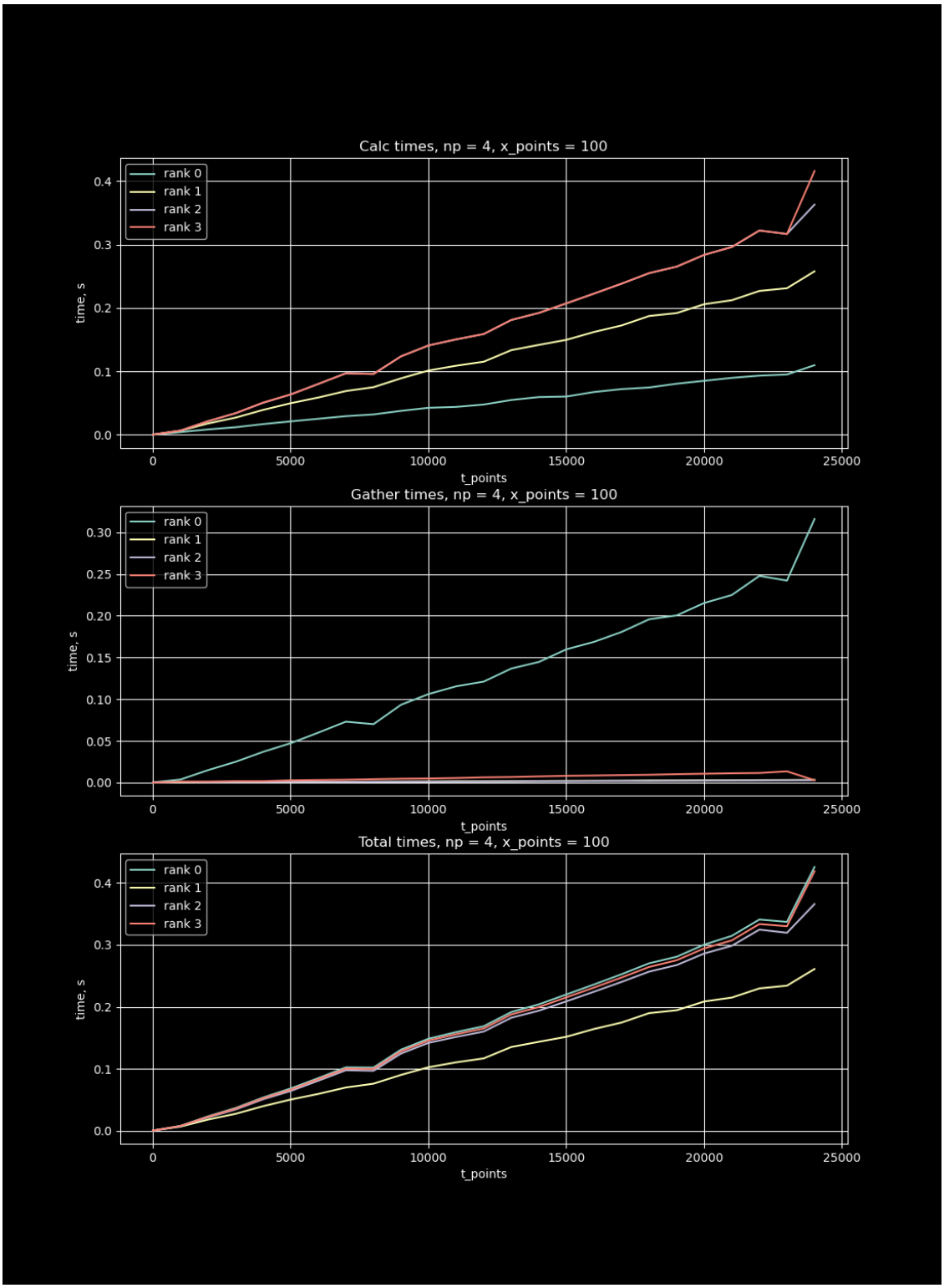
```
plt.subplot (311)
plt.grid ()
plt.title ("Calc times, np = {0}, x_points = {1}".format(n_proc,␣
 ↪x_points_at_t_var))
plt.xlabel ("t_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (t_points_var, times[0][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()

plt.subplot (312)
plt.grid ()
plt.title ("Gather times, np = {0}, x_points = {1}".format(n_proc,␣
 ↪x_points_at_t_var))
plt.xlabel ("t_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (t_points_var, times[1][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()

plt.subplot (313)
plt.grid ()
plt.title ("Total times, np = {0}, x_points = {1}".format(n_proc,␣
 ↪x_points_at_t_var))
plt.xlabel ("t_points")
plt.ylabel ("time, s")
for i in range(0, n_proc):
    plt.plot (t_points_var, times[2][i], 'C{0}'.format (i), label = 'rank {0}'.
 ↪format(i))
plt.legend ()
```

```
100%|      | 25/25 [02:30<00:00,  6.04s/it]
```

t_points	max calc time	max gather time	max total time
10	0.000282049	0.000344038	0.000513077
1010	0.00656009	0.00375891	0.00805998
2010	0.0213749	0.0149879	0.023428
3010	0.033957	0.0250289	0.0368881
4010	0.0507951	0.0369599	0.053792
5010	0.063601	0.047302	0.0684199
6010	0.0801179	0.059921	0.0851321
7010	0.096921	0.073107	0.102414
8010	0.0958769	0.0700629	0.102107
9010	0.123641	0.0933371	0.130996

10010	0.140868	0.106149	0.148702
11010	0.150398	0.115431	0.159331
12010	0.158785	0.121113	0.168808
13010	0.180981	0.13675	0.191594
14010	0.19212	0.144603	0.204094
15010	0.20721	0.159761	0.220091
16010	0.222529	0.168694	0.236128
17010	0.238227	0.180587	0.252617
18010	0.254901	0.195751	0.270316
19010	0.2651	0.200397	0.280924
20010	0.283704	0.215321	0.300454
21010	0.296028	0.22485	0.314579
22010	0.322077	0.247748	0.340983
23010	0.316698	0.242153	0.337147
24010	0.41588	0.315936	0.425711

[ ]: <matplotlib.legend.Legend at 0x7f38f5b49ba0>


Calc times, np = 4, x_points = 100
rank 0
rank 1
rank 2
rank 3
time, s
t_points
Gather times, np = 4, x_points = 100
rank 0
rank 1
rank 2
rank 3
time, s
t_points
Total times, np = 4, x_points = 100
rank 0
rank 1
rank 2
rank 3
time, s
t_points

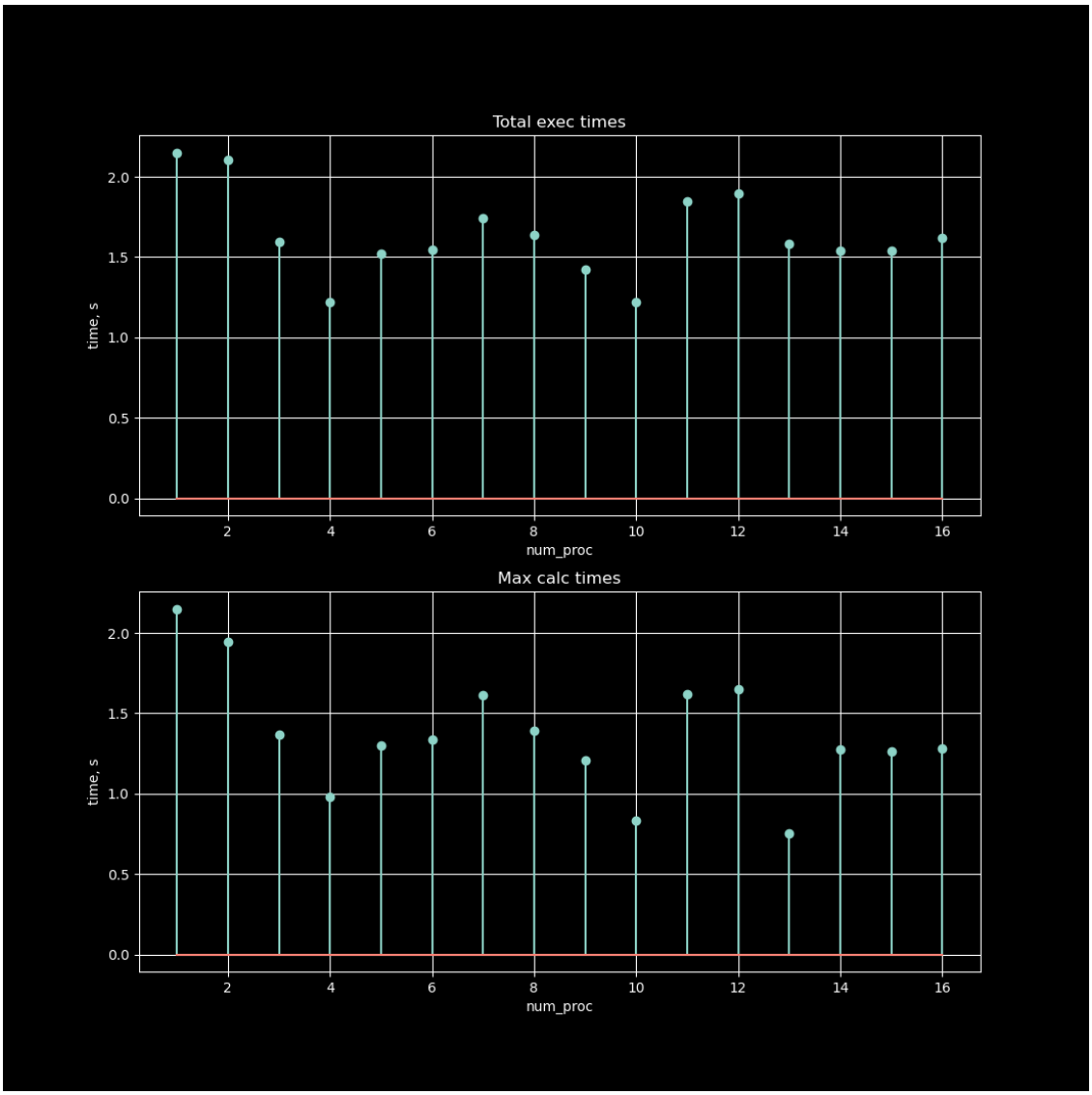
[ ]:
```
### np var at cluster
np_end = 16
np_var = np.arange (np_start, np_end + 1)
times = np.zeros ((3, np_end - np_start + 1))
i = np_start
tabledata = []
with tqdm(total = np_end - np_start + 1) as pbar:
    while i <= np_end:
        compile = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "NUM_PROC={0}".format (i), "ARGS=\"", "{0}".format␣
 ↪(x_points_at_np_var), "{0}".format (t_points_at_np_var), "{0}".format␣
 ↪(x_max), "{0}".format (t_max), "n\"", "-C", "./lab1/"], capture_output=True)
        time.sleep (2)
        run = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"make", "-C", "./lab1/", "run"], capture_output=True)
        time.sleep (6)
        result = subprocess.run (["sshpass", "-p", "omeunzimarod", "ssh", "-o␣
 ↪StrictHostKeyChecking=no", "-p", "52960", "b0190302@remote.vdi.mipt.ru",␣
 ↪"cat", "./lab1/stdout.txt"], capture_output=True, text=True)
        res_split = result.stdout.split ()
        max_calc = 0
        max_gather = 0
        max_total = 0
        for p in range (0, i - np_start + 1):
            if float (res_split[p * 4 + 1]) > max_calc:
                max_calc = float (res_split[p * 4 + 1])
            if float (res_split[p * 4 + 2]) > max_gather:
                max_gather = float (res_split[p * 4 + 2])
            if float (res_split[p * 4 + 3]) > max_total:
                max_total = float (res_split[p * 4 + 3])

        times[0][i - np_start] = max_calc
        times[1][i - np_start] = max_gather
        times[2][i - np_start] = max_total
        temp = []
        temp.append (i)
        temp.append (max_calc)
        temp.append (max_gather)
        temp.append (max_total)
        tabledata.append (temp)
        i = i + 1
        pbar.update (1)

print (tabulate (tabledata, headers = ["N proc", "max calc time", "max gather␣
 ↪time", "max total time"]))
```

```
plt.figure (figsize = [11, 11])

plt.subplot (211)
plt.grid ()
plt.title ("Total exec times")
plt.xlabel ("num_proc")
plt.ylabel ("time, s")
plt.stem (np_var, times[2])

plt.subplot (212)
plt.grid ()
plt.title ("Max calc times")
plt.xlabel ("num_proc")
plt.ylabel ("time, s")
plt.stem (np_var, times[0])
```

```
100%|      | 16/16 [03:10<00:00, 11.89s/it]
```

N proc	max calc time	max gather time	max total time
1	2.15079	0	2.15083
2	1.94212	1.12582	2.10425
3	1.37032	0.979814	1.59299
4	0.982759	0.775388	1.21844
5	1.30199	1.18031	1.52102
6	1.33592	1.26883	1.54367
7	1.61248	1.53915	1.74298
8	1.38917	1.42792	1.63661
9	1.20724	1.2363	1.42423
10	0.835033	0.942569	1.22249
11	1.61617	1.69365	1.84661
12	1.65276	1.75585	1.89826
13	0.751653	1.08658	1.57998
14	1.27527	1.41161	1.53743
15	1.26292	1.41828	1.53777
16	1.27859	1.50902	1.62052

[ ]: <StemContainer object of 3 artists>


Total exec times
time, s
num_proc
Max calc times
time, s
num_proc