# Module 3 Distributed and Hybrid Programming

## TaskM3.T1P: MPI, OpenMP and OpenCL Matrix Multiplication

**Let's look at sequential program durations-**

Runtime of sequential program of Matrix Multiplication with size of 20:

```
PS C:\Users\iftek\MatrixMultiply> g++ -o main.exe .\Matrix.cpp
PS C:\Users\iftek\MatrixMultiply> .\main.exe
Time taken for multiplication: 38 microseconds
Multiplication result is:
45463 55556 40773 41199 48536 51772 33181 47302 55705 49241 55163 44068 51319 44337 53852 39986 41583 40633 49107 48390
43231 55500 46331 39321 40208 50631 38276 41633 48555 45406 48473 40961 44373 39939 43867 30982 40412 47465 49319 44763
52887 55525 42942 44346 48550 46087 43690 39516 51032 56688 58947 43928 51873 51112 51149 47165 52738 44372 56029 62426
41902 45059 43308 35241 35647 36383 30909 30076 42116 34008 45046 33290 36493 42672 39909 39037 29885 38175 37812 46350
54016 53743 57483 50931 45460 50978 37414 45184 48706 53285 54835 48294 49195 43544 43969 42756 39896 44531 53066 54624
54387 52435 42891 49943 49015 43105 33517 43940 55883 55348 48060 46991 49465 54147 49798 37424 39495 42219 46272 55466
43273 46533 36844 45055 38723 43289 32060 39384 38746 46653 45161 36153 43374 39033 36756 31748 36706 38689 44004 52964
58354 59619 55282 57887 58894 51330 50329 45111 59548 58873 58956 52597 53042 49997 58520 53311 50860 61480 58245 63659
49376 52640 45449 41914 45847 44524 41306 45376 50128 47849 47203 40386 52284 41917 38012 45257 37210 46503 54252 58320
56826 56593 51425 48149 44307 54313 40154 48773 57483 55432 63945 50515 50123 50416 51812 47088 46674 47898 57375 58349
46408 55440 43361 40170 45673 50378 42308 39982 47300 50667 55428 40467 45486 40881 51201 42949 42868 47647 52359 50766
```

Runtime of sequential program of Matrix Multiplication with size of 100:

```
PS C:\Users\iftek\MatrixMultiply> g++ -fopenmp .\Matrix.cpp -o main.exe
PS C:\Users\iftek\MatrixMultiply> g++ -o main.exe .\Matrix.cpp
PS C:\Users\iftek\MatrixMultiply> .\main.exe
Time taken for multiplication: 4870 microseconds
Multiplication result is:
237212 236688 295161 260631 266487 270745 256425 256834 285088 251106 279737 278929 272851 273800 248242 260
39432 291308 279494 275380 251338 257324 258046 284751 235246 245304 283901 269377 256186 261305 237734 2729
8128 257984 285144 231202 280222 255417 243153 263618 232489 265993 272390 259728 243860 260013 244272 26008
932 261679 291348 258776 263932 277139 279406 244603 266498 258806 281271 238237 276334 263613 268469 277968
07 262130 261550 272409 239933 288085 254967 271389 243548 255171 272448 243194 239596 266813 273739 260726
```

**Let's look at program durations after distributing work on nodes using MPI-**

```
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 467376 microseconds
12765 20055 12552 19263
3132 10366 3108 10379
14243 19095 12483 4006
13588 20100 12433 3709
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 464544 microseconds
6478 7277 9979 6149
3412 4044 7837 3585
13910 16733 16851 11067
13406 15282 15886 9282
mpiuser@SIT315-Head:~/Cloud$
```

Matrix size 4 processes 6. **Duration: 464544ms**

```
mpiuser@SIT315-Head:~/Cloud$ mpicxx ./Matrix.cpp
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 509384 microseconds
54254 53890 54593 47150 53723 40547 28380 48326 50132 44487 41414 38988 42374 42172 46033 40708 45739 38419 50828 46494
51069 52684 45852 45100 52750 42855 33799 49447 46521 47092 44366 43584 42620 33977 41479 45311 52945 47698 45145 39968
54667 67968 72852 54974 52387 59775 47601 58051 56811 58567 66346 49527 51196 39967 72023 51902 66027 59234 57334 41664
42194 58437 48006 47218 56300 49848 49272 33417 48891 51480 59430 57585 55434 47318 0 0 97 0 50706 33027
33434 53081 39438 39606 48983 50745 37708 33617 45863 39190 47173 41493 44930 43653 0 0 97 0 44733 31641
37043 54895 35981 31659 39082 47089 35160 29793 39599 32859 51125 42396 46708 60729 56097 54593 51695 43165 39194 48981
47040 44025 49782 40744 55199 48752 54998 48491 0 0 97 0 57572 61301 63918 52297 53228 53236 33344 50730
50456 35312 52860 47407 56071 57879 49725 46595 0 0 97 0 49276 60331 57391 44723 52380 44413 34909 42445
47419 39590 47533 41266 50523 53269 40598 34751 31716 32463 37955 28138 18913 35595 40804 27589 30227 28581 32764 21145
36256 40493 0 0 97 0 75054 53975 57977 57162 66097 53049 40833 64985 63385 51318 57235 58677 51284 34283
```

Matrix size 20 processes 6. **Duration: 509384ms**

```
mpiuser@SIT315-Head:~/Cloud$ mpicxx ./Matrix.cpp
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 446132 microseconds
250887 227493 242358 247675 245308 241220 207131 254089 241538 205997 206372 236144 226607 247816 210423 226904 231898 233200 241908 249029 230595 253218 245828 214505 241973 252207 2
23881 220575 235651 255424 270467 240356 198953 263485 202448 240110 262937 235060 249212 218184 207824 257317 231551 264326 240794 215297 248779 217128 213048 260213 235060 229643 22
6489 231104 205483 228043 198598 227040 254486 223013 250984 241290 240821 256352 235548 232697 250071 256463 257500 232588 226064 227603 239518 224355 250121 245305 252792 247192 244
604 248133 242888 243167 252206 216734 236923 252296 231621 195241 239956 266524 242655 252460 251610 241548 225175 240260 230001 232967 219286 222175
278077 234019 273186 253436 261000 252126 242342 250966 237863 217323 235823 245520 231963 237459 237376 249146 268013 256881 241948 282268 244386 276628 271130 231862 240577 257812 2
51246 246102 276453 264616 273645 260599 209599 266368 240225 268161 279363 255362 268539 245112 218505 267059 241633 274231 261872 212419 250932 246509 236486 287429 239678 256314 24
7207 255073 226916 247162 231671 252910 276975 247971 251890 261171 268516 255780 245287 265861 282766 257091 263208 233440 252806 242287 232074 252556 262307 270270 293229 277830 255
091 268628 255353 274884 264671 230928 240647 260816 256647 238167 247738 268583 262270 256416 255033 256628 253090 257214 256348 262998 247968 237230
252583 230641 243945 231559 263668 245774 225911 234701 251884 231250 206027 248999 239845 227526 213781 235161 239743 252647 254068 274713 236739 246023 257970 214470 245916 257492 2
38024 223685 251529 256065 284166 233647 193184 266481 245656 236865 254251 237529 245136 224937 232614 260427 240352 271123 256110 222557 238423 241524 231310 277780 235840 247559 22
5295 236092 215692 228592 217094 259163 262582 234200 254914 262534 239271 256014 226398 244447 253830 245432 264169 236450 248937 236931 228987 231166 243008 242837 277422 252931 241
898 242005 264997 251897 249171 235572 228574 246964 247668 221119 240603 262803 259469 263408 235485 234302 228905 240467 244178 267785 227376 241614
242084 235004 243682 235455 258423 224521 223384 223038 246227 200681 208228 228186 219653 248909 207628 220185 234874 246415 232574 246523 234740 246544 237705 224589 247969 241228 2
28551 216321 252219 251081 252997 247503 196698 238085 216234 237730 251512 243634 246994 223293 222394 235475 223704 268319 240978 195994 225971 232238 232028 266055 230779 231593 20
9837 238458 204349 220504 182890 241140 244957 225285 229844 246039 239050 250200 234521 235236 258117 246807 229233 226683 240121 227816 212277 230315 228661 231463 255725 252403 253
501 227709 241563 241334 250685 222778 254174 249668 251732 220605 223576 256814 252590 250745 232645 238809 234993 231530 230520 247026 229591 220419
```

Matrix size 100 processes 6. **Duration: 446132ms**

**Hence, it shows that even with increasing matrix size, the time duration is still less. By distributing work on the nodes, we are significantly getting good performance and it will perform good for even for larger matrix sizes.**

**Let's look at program durations after making a hybrid program using MPI & OpenMP-**

```
mpiuser@SIT315-Head:~/Cloud$ mpicxx -fopenmp ./Matrix.cpp
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 697597 microseconds
46589 45331 41447 43718 42885 43686 41050 30902 40091 48101 54186 47530 36438 46672 43432 40104 43653 36361 46888 27238
34847 31798 30283 40630 35248 41741 27541 22293 35172 30347 41037 31289 31351 45560 32896 25883 27651 28259 45100 20650
46294 45204 45394 54077 51852 52663 53049 35027 36191 48680 48917 43247 38872 48907 42432 44421 42657 33030 55483 47449
43478 30231 40409 55780 56951 53750 44567 55735 40703 46599 42484 42194 58248 40989 0 0 97 0 48128 38462
28826 30515 41816 47811 56866 44391 34921 55685 39447 44609 38234 39682 47256 33673 0 0 97 0 51045 36880
31655 30552 37877 47774 56665 46825 32293 55466 40838 39320 38321 42642 37450 47171 39261 49261 48283 51447 45204 38806
38350 54269 50368 39059 42685 39013 53001 21656 0 0 97 0 46931 44865 44556 52411 53697 52445 41654 41619
```

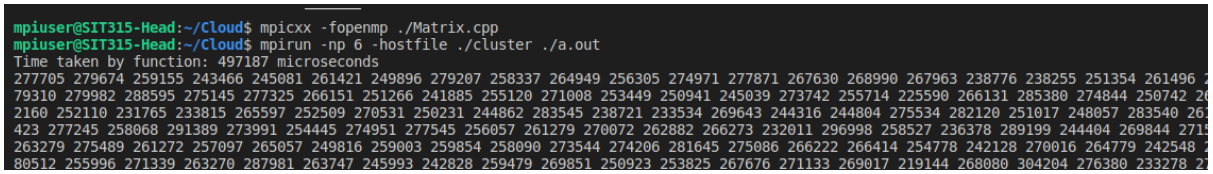
Matrix size 20, processes 6, threads 4. **Duration: 697597ms**

```
mpiuser@SIT315-Head:~/Cloud$ mpicxx -fopenmp ./Matrix.cpp
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 491434 microseconds
47961 54827 69013 49047 41289 56159 51253 61154 44959 57859 55846 61645 58497 53904 63720 54362 49845 58402 51207 44232
45092 49020 62890 48284 36533 57122 44309 52383 42793 48200 41309 60130 54811 44313 58762 47849 38286 54711 36313 40085
38440 41597 57337 37767 34142 50546 41323 48671 39224 40119 42267 50880 47604 37718 51006 41974 36838 46780 35592 41976
51569 37838 31499 40784 44350 53476 36038 32159 43664 35675 31534 45097 36723 31916 0 0 97 0 42579 37956
43915 38504 37237 45431 36745 43351 41364 31333 38955 41276 40608 38910 31213 33574 0 0 97 0 40997 46497
55242 43747 40317 55460 41154 53844 47982 34043 49592 45359 41442 46063 22133 32144 39592 27549 22589 30213 39398 37370
47358 35216 44823 43643 25357 28788 34298 25870 0 0 97 0 28954 34130 45554 27562 27728 33733 35919 41302
46997 33711 43370 44704 35376 36575 35144 32013 0 0 97 0 28592 39097 49232 31690 36716 42176 41821 45370
51867 37338 43316 37527 24883 40913 43676 44594 46255 34167 30202 35814 46106 36490 31712 43653 38402 43804 50018 32946
36062 31847 0 0 97 0 48824 51020 57257 46404 33683 47716 52780 49640 37319 54030 50607 53459 51054 38412
40734 43399 0 0 97 0 37921 44599 49308 39829 28226 40697 45397 42894 37575 52569 42474 49836 47514 32774
60255 62772 73702 56502 49629 67273 59503 71686 56104 64312 56793 76282 79296 57629 73696 62318 48580 68726 51316 50115
31734 32816 36716 24048 22434 30499 34501 36439 31809 32297 30206 37993 47820 31662 37971 42545 24962 30730 32805 28755
```

Matrix size 20, processes 6, threads 6. **Duration: 491434ms**

```
mpiuser@SIT315-Head:~/Cloud$ mpicxx -fopenmp ./Matrix.cpp
mpiuser@SIT315-Head:~/Cloud$ mpirun -np 6 -hostfile ./cluster ./a.out
Time taken by function: 611012 microseconds
207045 221249 226745 229516 227051 236866 192806 231903 216719 194524 240885 236831 223721 229366 236051 239117 231800 221849 242395 228042 191193 216147 222
16479 201431 194443 203248 223419 229719 216181 229538 238165 245627 231810 232499 233882 206042 241922 243645 203894 223725 191613 219304 219617 238539 20868
6324 205518 207080 238402 239010 193107 206224 229269 230815 240700 223550 225708 222245 258817 199530 247454 220584 208398 243435 230977 226417 269937 221740
381 205232 215684 232120 226266 224454 248153 237631 220556 236795 214695 228446 234321 239631 238088 215091 228884 216222 198122 223834 223297 229681
227571 246027 255729 250815 250583 262680 219944 236465 240770 241996 254030 238786 236527 239055 247153 256539 245280 261985 250212 262507 242754 225025 2314
28218 216682 223695 225786 251594 228374 225942 267574 264249 271986 240741 254361 259464 235616 274656 253468 217905 249863 223280 261932 226227 272206 22573
3507 236797 232047 264055 257880 229892 232789 239730 252420 232888 259805 238589 239575 274860 216155 270614 218919 243791 246847 234375 253132 294315 23054
```

Matrix size 100, processes 6, threads 4. **Duration: 611012ms**




Matrix size 100, processes 6, threads 6. **Duration: 497187ms**

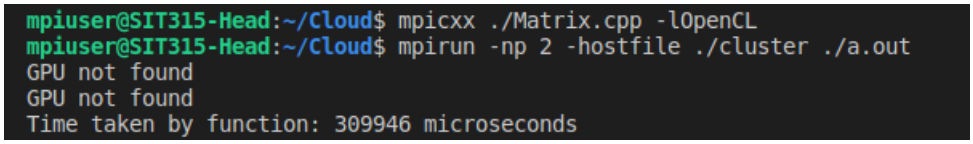
Evaluation

Matrix size 100 processes 6. Duration: 446132ms**: ONLY MPI**

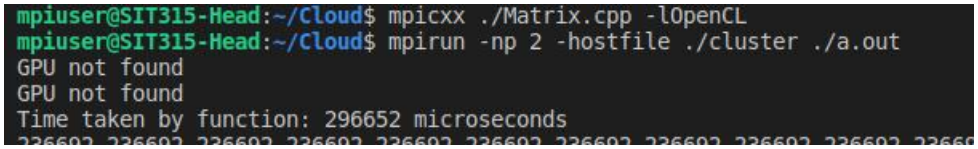
Matrix size 100, processes 6, threads 6. Duration: 497187ms: **MPI+OPENMP**

Thus, the durations are quite similar, and we can conclude that performance is similar with hybrid approach.

**Let's look at program durations after making a hybrid program using MPI & OPENCL-**




Matrix size 20 processes 2. **Duration: 309946ms**




Matrix size 100 processes 2. **Duration: 296652ms**

Evaluation

Matrix size 100 processes 6. Duration: 446132ms**: ONLY MPI**

Matrix size 100, processes 6, threads 6. Duration: 497187ms: **MPI+OPENMP**

Matrix size 100 processes 2. Duration: 296652ms: **MPI+OpenCL**

**Conclusion**

As we can see, MPI+OpenCL combination is working the best in terms of parallelising the matrix multiplication program! There is a significant improvement in performance.