Parallel Homework #1

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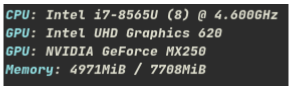
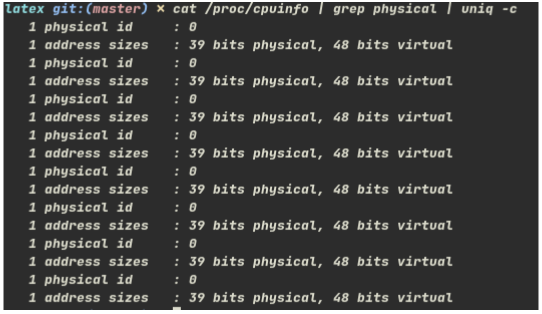
Figure 1: Here is the hardware's information



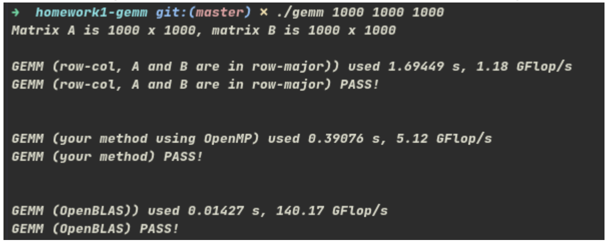
```
CPU: Intel i7-8565U (8) @ 4.600GHz
GPU: Intel UHD Graphics 620
GPU: NVIDIA GeForce MX250
Memory: 4971MiB / 7708MiB
```

Figure 2: Here is the cupcores' information



```
latex git:(master) × cat /proc/cpuinfo | grep physical | uniq -c
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
   1 physical id     : 0
   1 address sizes   : 39 bits physical, 48 bits virtual
```

Figure 3: Here is the test runing



```
→  homework1-gemm git:(master) × ./gemm 1000 1000 1000
Matrix A is 1000 x 1000, matrix B is 1000 x 1000

GEMM (row-col, A and B are in row-major)) used 1.69449 s, 1.18 GFlop/s
GEMM (row-col, A and B are in row-major) PASS!


GEMM (your method using OpenMP) used 0.39076 s, 5.12 GFlop/s
GEMM (your method) PASS!


GEMM (OpenBLAS)) used 0.01427 s, 140.17 GFlop/s
GEMM (OpenBLAS) PASS!
```

To get the following data is annoying, for there are many operations to do.

And to write a script will reduce a lot of work.

Such as:

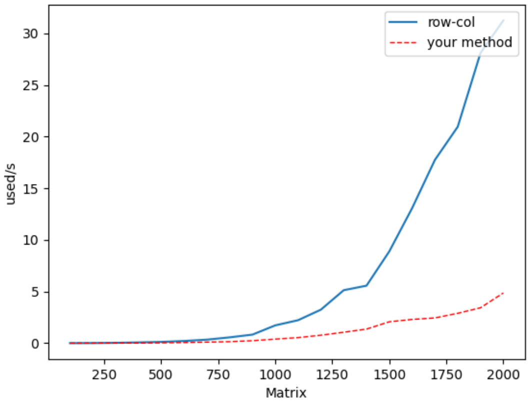
```
./gemm 100 100 100 > 1.txt
./gemm 200 200 200 >> 1.txt
./gemm 300 300 300 >> 1.txt
./gemm 400 400 400 >> 1.txt
./gemm 500 500 500 >> 1.txt
./gemm 600 600 600 >> 1.txt
./gemm 700 700 700 >> 1.txt
./gemm 800 800 800 >> 1.txt
./gemm 900 900 900 >> 1.txt
./gemm 1000 1000 1000 >> 1.txt
./gemm 1100 1100 1100 >> 1.txt
./gemm 1200 1200 1200 >> 1.txt
./gemm 1300 1300 1300 >> 1.txt
./gemm 1400 1400 1400 >> 1.txt
./gemm 1500 1500 1500 >> 1.txt
./gemm 1600 1600 1600 >> 1.txt
./gemm 1700 1700 1700 >> 1.txt
./gemm 1800 1800 1800 >> 1.txt
./gemm 1900 1900 1900 >> 1.txt
./gemm 2000 2000 2000 >> 1.txt
```

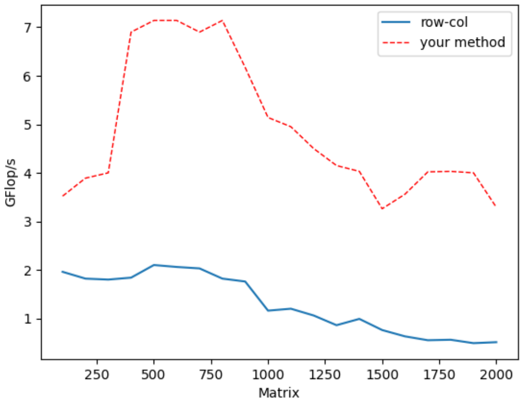
save it as 1.sh, then ./1.sh(you may need chmod +x 1.sh)
To get the data for painting, I find a good command:

```
echo $(grep -Eo '[0-9\.]+' myfile.txt) >output.txt
```

1 the original serial code

```
GEMM (row-col, A and B are in row-major)) used 0.00102 s, 1.96 GFlop/s
    GEMM (your method)) used 0.00057 s, 3.52 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.00880 s, 1.82 GFlop/s
    GEMM (your method)) used 0.00412 s, 3.89 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.02998 s, 1.80 GFlop/s
    GEMM (your method)) used 0.01348 s, 4.00 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.06944 s, 1.84 GFlop/s
    GEMM (your method)) used 0.01855 s, 6.90 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.11889 s, 2.10 GFlop/s
    GEMM (your method)) used 0.03502 s, 7.14 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.20949 s, 2.06 GFlop/s
    GEMM (your method)) used 0.06048 s, 7.14 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.33802 s, 2.03 GFlop/s
    GEMM (your method)) used 0.09937 s, 6.90 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.56159 s, 1.82 GFlop/s
    GEMM (your method)) used 0.14351 s, 7.14 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 0.82811 s, 1.76 GFlop/s
    GEMM (your method)) used 0.23620 s, 6.17 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 1.72386 s, 1.16 GFlop/s
    GEMM (your method)) used 0.38879 s, 5.14 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 2.22392 s, 1.20 GFlop/s
    GEMM (your method)) used 0.53795 s, 4.95 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 3.24518 s, 1.06 GFlop/s
    GEMM (your method)) used 0.76877 s, 4.50 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 5.12792 s, 0.86 GFlop/s
    GEMM (your method)) used 1.05956 s, 4.15 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 5.56816 s, 0.99 GFlop/s
    GEMM (your method)) used 1.36282 s, 4.03 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 8.89214 s, 0.76 GFlop/s
    GEMM (your method)) used 2.07073 s, 3.26 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 13.07524 s, 0.63 GFlop/s
    GEMM (your method)) used 2.29913 s, 3.56 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 17.75225 s, 0.55 GFlop/s
    GEMM (your method)) used 2.44229 s, 4.02 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 20.95926 s, 0.56 GFlop/s
    GEMM (your method)) used 2.89090 s, 4.03 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 28.11750 s, 0.49 GFlop/s
    GEMM (your method)) used 3.42984 s, 4.00 GFlop/s
    GEMM (row-col, A and B are in row-major)) used 31.26064 s, 0.51 GFlop/s
    GEMM (your method)) used 4.86276 s, 3.29 GFlop/s
```





2 several kinds of serial codes in exchange order

2.1 i, ki, j

```
used 0.00056 s, 3.57 GFlop/s
used 0.00412 s, 3.88 GFlop/s
used 0.01338 s, 4.03 GFlop/s
used 0.03295 s, 3.88 GFlop/s
used 0.03635 s, 6.88 GFlop/s
used 0.06897 s, 6.26 GFlop/s
used 0.09563 s, 7.17 GFlop/s
used 0.15294 s, 6.70 GFlop/s
used 0.23971 s, 6.08 GFlop/s
used 0.39362 s, 5.08 GFlop/s
used 0.57278 s, 4.65 GFlop/s
```

```
    used 0.74118 s, 4.66 GFlop/s
    used 1.01079 s, 4.35 GFlop/s
    used 1.38078 s, 3.97 GFlop/s
    used 1.69293 s, 3.99 GFlop/s
    used 2.00908 s, 4.08 GFlop/s
    used 2.46988 s, 3.98 GFlop/s
    used 3.07154 s, 3.80 GFlop/s
    used 3.60899 s, 3.80 GFlop/s
    used 4.24184 s, 3.77 GFlop/s
```

2.2 i, j, ki

```
used 0.00133 s, 1.51 GFlop/s
    used 0.01035 s, 1.55 GFlop/s
    used 0.03485 s, 1.55 GFlop/s
    used 0.06523 s, 1.96 GFlop/s
    used 0.12682 s, 1.97 GFlop/s
    used 0.21508 s, 2.01 GFlop/s
    used 0.35496 s, 1.93 GFlop/s
    used 0.61810 s, 1.66 GFlop/s
    used 0.94968 s, 1.54 GFlop/s
    used 1.77247 s, 1.13 GFlop/s
    used 2.44696 s, 1.09 GFlop/s
    used 3.23357 s, 1.07 GFlop/s
    used 5.82691 s, 0.75 GFlop/s
    used 6.08800 s, 0.90 GFlop/s
    used 8.87992 s, 0.76 GFlop/s
    used 13.04372 s, 0.63 GFlop/s
    used 17.98408 s, 0.55 GFlop/s
    used 22.23343 s, 0.52 GFlop/s
    used 29.17877 s, 0.47 GFlop/s
    used 30.89221 s, 0.52 GFlop/s
```

2.3 ki, i, j

```
used 0.00053 s, 3.78 GFlop/s
    used 0.00406 s, 3.94 GFlop/s
    used 0.03598 s, 1.50 GFlop/s
    used 0.02632 s, 4.86 GFlop/s
    used 0.03591 s, 6.96 GFlop/s
    used 0.06295 s, 6.86 GFlop/s
    used 0.10332 s, 6.64 GFlop/s
    used 0.18250 s, 5.61 GFlop/s
    used 0.26754 s, 5.45 GFlop/s
    used 0.43052 s, 4.65 GFlop/s
    used 0.67797 s, 3.93 GFlop/s
    used 0.97233 s, 3.55 GFlop/s
    used 1.36233 s, 3.23 GFlop/s
    used 2.00249 s, 2.74 GFlop/s
    used 2.40162 s, 2.81 GFlop/s
    used 2.64902 s, 3.09 GFlop/s
    used 4.22108 s, 2.33 GFlop/s
    used 4.12343 s, 2.83 GFlop/s
    used 6.65517 s, 2.06 GFlop/s
    used 5.77122 s, 2.77 GFlop/s
```

2.4 ki, j, i

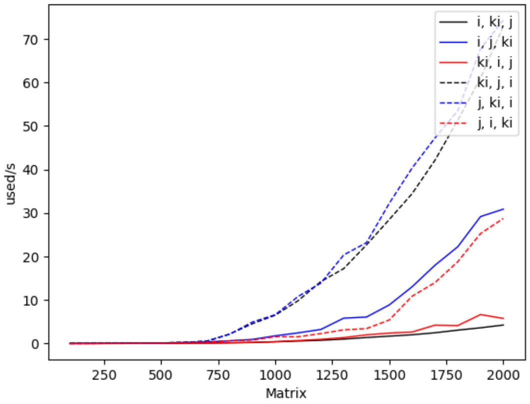
```
used 0.00098 s, 2.04 GFlop/s
    used 0.00928 s, 1.72 GFlop/s
    used 0.03800 s, 1.42 GFlop/s
    used 0.08881 s, 1.44 GFlop/s
    used 0.13573 s, 1.84 GFlop/s
    used 0.24446 s, 1.77 GFlop/s
    used 0.55681 s, 1.23 GFlop/s
    used 2.19454 s, 0.47 GFlop/s
    used 4.55634 s, 0.32 GFlop/s
    used 6.51371 s, 0.31 GFlop/s
    used 9.83481 s, 0.27 GFlop/s
    used 14.24950 s, 0.24 GFlop/s
    used 17.21507 s, 0.26 GFlop/s
    used 22.67421 s, 0.24 GFlop/s
    used 28.51237 s, 0.24 GFlop/s
    used 34.44606 s, 0.24 GFlop/s
    used 42.11570 s, 0.23 GFlop/s
    used 51.29658 s, 0.23 GFlop/s
    used 61.06770 s, 0.22 GFlop/s
    used 72.93995 s, 0.22 GFlop/s
```

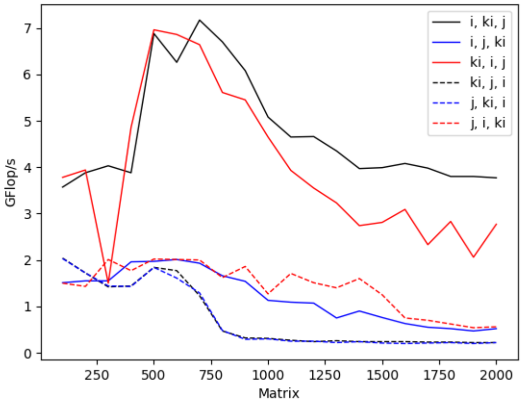
2.5 j, ki, i

```
used 0.00098 s, 2.03 GFlop/s
    used 0.00932 s, 1.72 GFlop/s
    used 0.03746 s, 1.44 GFlop/s
    used 0.08922 s, 1.43 GFlop/s
    used 0.13562 s, 1.84 GFlop/s
    used 0.26870 s, 1.61 GFlop/s
    used 0.53022 s, 1.29 GFlop/s
    used 2.11891 s, 0.48 GFlop/s
    used 4.94585 s, 0.29 GFlop/s
    used 6.61430 s, 0.30 GFlop/s
    used 10.81202 s, 0.25 GFlop/s
    used 13.89475 s, 0.25 GFlop/s
    used 20.35850 s, 0.22 GFlop/s
    used 23.19168 s, 0.24 GFlop/s
    used 32.24834 s, 0.21 GFlop/s
    used 40.34462 s, 0.20 GFlop/s
    used 47.24516 s, 0.21 GFlop/s
    used 53.48966 s, 0.22 GFlop/s
    used 67.74452 s, 0.20 GFlop/s
    used 74.35895 s, 0.22 GFlop/s
```

2.6 j, i, ki

```
used 0.00133 s, 1.50 GFlop/s
    used 0.01118 s, 1.43 GFlop/s
    used 0.02688 s, 2.01 GFlop/s
    used 0.07242 s, 1.77 GFlop/s
    used 0.12366 s, 2.02 GFlop/s
    used 0.21535 s, 2.01 GFlop/s
    used 0.34364 s, 2.00 GFlop/s
    used 0.63364 s, 1.62 GFlop/s
    used 0.78422 s, 1.86 GFlop/s
    used 1.57273 s, 1.27 GFlop/s
    used 1.55374 s, 1.71 GFlop/s
    used 2.28916 s, 1.51 GFlop/s
    used 3.14497 s, 1.40 GFlop/s
    used 3.43000 s, 1.60 GFlop/s
    used 5.41349 s, 1.25 GFlop/s
    used 10.87437 s, 0.75 GFlop/s
    used 13.99641 s, 0.70 GFlop/s
    used 18.79972 s, 0.62 GFlop/s
    used 25.27928 s, 0.54 GFlop/s
    used 28.75452 s, 0.56 GFlop/s
```





3 The parallel code of adding OpenMP instruction statements on different for loops

3.1 On the outermost layer

```
GEMM (your method using OpenMP) used 0.02339 s, 0.09 GFlop/s
    GEMM (your method using OpenMP) used 0.04390 s, 0.36 GFlop/s
    GEMM (your method using OpenMP) used 0.02608 s, 2.07 GFlop/s
    GEMM (your method using OpenMP) used 0.02916 s, 4.39 GFlop/s
    GEMM (your method using OpenMP) used 0.00826 s, 30.27 GFlop/s
    GEMM (your method using OpenMP) used 0.01504 s, 28.73 GFlop/s
    GEMM (your method using OpenMP) used 0.02274 s, 30.17 GFlop/s
    GEMM (your method using OpenMP) used 0.05594 s, 18.30 GFlop/s
    GEMM (your method using OpenMP) used 0.05195 s, 28.06 GFlop/s
    GEMM (your method using OpenMP) used 0.07657 s, 26.12 GFlop/s
    GEMM (your method using OpenMP) used 0.10954 s, 24.30 GFlop/s
    GEMM (your method using OpenMP) used 0.14669 s, 23.56 GFlop/s
    GEMM (your method using OpenMP) used 0.23959 s, 18.34 GFlop/s
    GEMM (your method using OpenMP) used 0.23676 s, 23.18 GFlop/s
    GEMM (your method using OpenMP) used 0.29352 s, 23.00 GFlop/s
    GEMM (your method using OpenMP) used 0.35728 s, 22.93 GFlop/s
    GEMM (your method using OpenMP) used 0.55337 s, 17.76 GFlop/s
    GEMM (your method using OpenMP) used 0.55028 s, 21.20 GFlop/s
    GEMM (your method using OpenMP) used 0.60977 s, 22.50 GFlop/s
    GEMM (your method using OpenMP) used 1.02352 s, 15.63 GFlop/s
```

3.2 On the middle layer

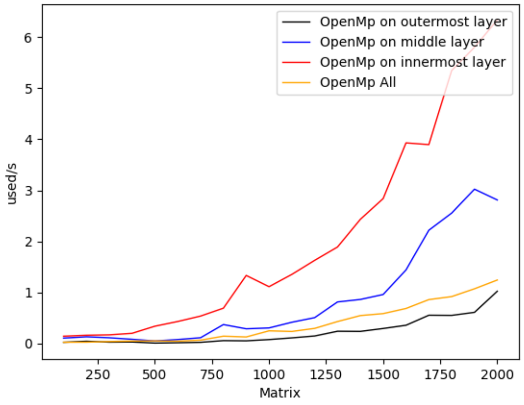
```
GEMM (your method using OpenMP) used 0.10483 s, 0.02 GFlop/s
    GEMM (your method using OpenMP) used 0.13009 s, 0.12 GFlop/s
    GEMM (your method using OpenMP) used 0.11149 s, 0.48 GFlop/s
    GEMM (your method using OpenMP) used 0.08190 s, 1.56 GFlop/s
    GEMM (your method using OpenMP) used 0.04915 s, 5.09 GFlop/s
    GEMM (your method using OpenMP) used 0.07722 s, 5.59 GFlop/s
    GEMM (your method using OpenMP) used 0.11242 s, 6.10 GFlop/s
    GEMM (your method using OpenMP) used 0.37099 s, 2.76 GFlop/s
    GEMM (your method using OpenMP) used 0.28761 s, 5.07 GFlop/s
    GEMM (your method using OpenMP) used 0.30444 s, 6.57 GFlop/s
    GEMM (your method using OpenMP) used 0.41652 s, 6.39 GFlop/s
    GEMM (your method using OpenMP) used 0.50659 s, 6.82 GFlop/s
    GEMM (your method using OpenMP) used 0.81366 s, 5.40 GFlop/s
    GEMM (your method using OpenMP) used 0.86263 s, 6.36 GFlop/s
    GEMM (your method using OpenMP) used 0.95994 s, 7.03 GFlop/s
    GEMM (your method using OpenMP) used 1.44060 s, 5.69 GFlop/s
    GEMM (your method using OpenMP) used 2.21802 s, 4.43 GFlop/s
    GEMM (your method using OpenMP) used 2.55399 s, 4.57 GFlop/s
    GEMM (your method using OpenMP) used 3.02265 s, 4.54 GFlop/s
    GEMM (your method using OpenMP) used 2.81095 s, 5.69 GFlop/s
```

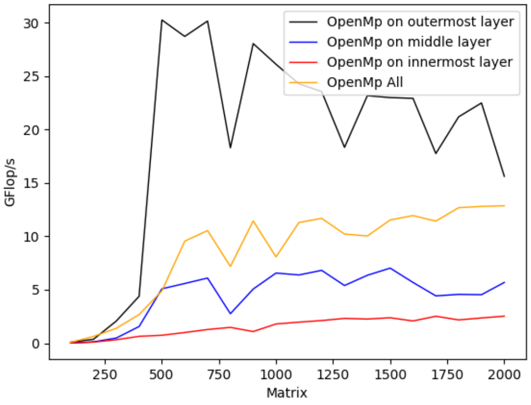
3.3 On the innermost layer

```
GEMM (your method using OpenMP) used 0.14213 s, 0.01 GFlop/s
    GEMM (your method using OpenMP) used 0.16077 s, 0.10 GFlop/s
    GEMM (your method using OpenMP) used 0.16873 s, 0.32 GFlop/s
    GEMM (your method using OpenMP) used 0.19918 s, 0.64 GFlop/s
    GEMM (your method using OpenMP) used 0.33860 s, 0.74 GFlop/s
    GEMM (your method using OpenMP) used 0.43110 s, 1.00 GFlop/s
    GEMM (your method using OpenMP) used 0.53695 s, 1.28 GFlop/s
    GEMM (your method using OpenMP) used 0.69128 s, 1.48 GFlop/s
    GEMM (your method using OpenMP) used 1.33319 s, 1.09 GFlop/s
    GEMM (your method using OpenMP) used 1.11235 s, 1.80 GFlop/s
    GEMM (your method using OpenMP) used 1.35365 s, 1.97 GFlop/s
    GEMM (your method using OpenMP) used 1.62872 s, 2.12 GFlop/s
    GEMM (your method using OpenMP) used 1.88995 s, 2.32 GFlop/s
    GEMM (your method using OpenMP) used 2.43175 s, 2.26 GFlop/s
    GEMM (your method using OpenMP) used 2.83890 s, 2.38 GFlop/s
    GEMM (your method using OpenMP) used 3.92916 s, 2.08 GFlop/s
    GEMM (your method using OpenMP) used 3.89522 s, 2.52 GFlop/s
    GEMM (your method using OpenMP) used 5.34578 s, 2.18 GFlop/s
    GEMM (your method using OpenMP) used 5.80137 s, 2.36 GFlop/s
    GEMM (your method using OpenMP) used 6.33616 s, 2.53 GFlop/s
```

3.4 All have OpenMp

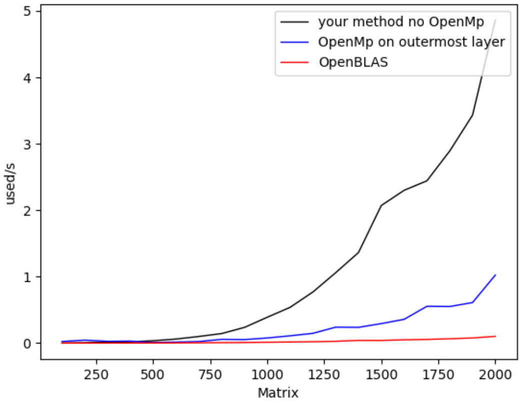
```
GEMM (your method using OpenMP) used 0.02438 s, 0.08 GFlop/s
    GEMM (your method using OpenMP) used 0.02548 s, 0.63 GFlop/s
    GEMM (your method using OpenMP) used 0.03873 s, 1.39 GFlop/s
    GEMM (your method using OpenMP) used 0.04785 s, 2.68 GFlop/s
    GEMM (your method using OpenMP) used 0.05105 s, 4.90 GFlop/s
    GEMM (your method using OpenMP) used 0.04522 s, 9.55 GFlop/s
    GEMM (your method using OpenMP) used 0.06505 s, 10.55 GFlop/s
    GEMM (your method using OpenMP) used 0.14264 s, 7.18 GFlop/s
    GEMM (your method using OpenMP) used 0.12730 s, 11.45 GFlop/s
    GEMM (your method using OpenMP) used 0.24761 s, 8.08 GFlop/s
    GEMM (your method using OpenMP) used 0.23549 s, 11.30 GFlop/s
    GEMM (your method using OpenMP) used 0.29567 s, 11.69 GFlop/s
    GEMM (your method using OpenMP) used 0.42988 s, 10.22 GFlop/s
    GEMM (your method using OpenMP) used 0.54662 s, 10.04 GFlop/s
    GEMM (your method using OpenMP) used 0.58515 s, 11.54 GFlop/s
    GEMM (your method using OpenMP) used 0.68546 s, 11.95 GFlop/s
    GEMM (your method using OpenMP) used 0.85964 s, 11.43 GFlop/s
    GEMM (your method using OpenMP) used 0.91883 s, 12.69 GFlop/s
    GEMM (your method using OpenMP) used 1.07123 s, 12.81 GFlop/s
    GEMM (your method using OpenMP) used 1.24310 s, 12.87 GFlop/s
```

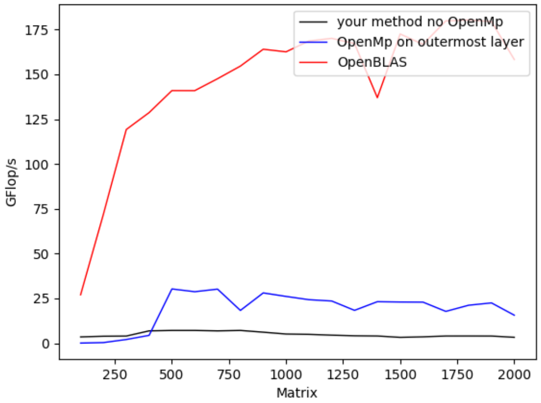




4 the parallel code of OpenBLAS

```
GEMM (OpenBLAS)) used 0.00007 s, 27.03 GFlop/s
    GEMM (OpenBLAS)) used 0.00022 s, 72.07 GFlop/s
    GEMM (OpenBLAS)) used 0.00045 s, 119.21 GFlop/s
    GEMM (OpenBLAS)) used 0.00100 s, 128.64 GFlop/s
    GEMM (OpenBLAS)) used 0.00177 s, 140.92 GFlop/s
    GEMM (OpenBLAS)) used 0.00307 s, 140.90 GFlop/s
    GEMM (OpenBLAS)) used 0.00465 s, 147.56 GFlop/s
    GEMM (OpenBLAS)) used 0.00662 s, 154.59 GFlop/s
    GEMM (OpenBLAS)) used 0.00889 s, 163.99 GFlop/s
    GEMM (OpenBLAS)) used 0.01230 s, 162.54 GFlop/s
    GEMM (OpenBLAS)) used 0.01579 s, 168.59 GFlop/s
    GEMM (OpenBLAS)) used 0.02032 s, 170.06 GFlop/s
    GEMM (OpenBLAS)) used 0.02628 s, 167.17 GFlop/s
    GEMM (OpenBLAS)) used 0.04007 s, 136.96 GFlop/s
    GEMM (OpenBLAS)) used 0.03913 s, 172.50 GFlop/s
    GEMM (OpenBLAS)) used 0.04913 s, 166.73 GFlop/s
    GEMM (OpenBLAS)) used 0.05465 s, 179.79 GFlop/s
    GEMM (OpenBLAS)) used 0.06469 s, 180.31 GFlop/s
    GEMM (OpenBLAS)) used 0.07646 s, 179.42 GFlop/s
    GEMM (OpenBLAS)) used 0.10112 s, 158.23 GFlop/s
```





5 Original GEMM code optimized in any way

I don't think of a better way for speeding up the matrix multiplication. For the code, the only way I can optimized is the check results... As long as a number is fault, break from the loop. But it seems meaningless if you need the sum of the wrong numbers.

```
    int count2 = 0;
      for (int i = 0; i < m * n; i++)
          if (C_golden[i] != C_yours[i])
              count2++;
      if (count2 == 0)
          printf("GEMM (your method) PASS!\n\n");
      else
          printf("GEMM (your method) NOT PASS!\n\n");
```

to change:

```
int count2 = 0;
  for (int i = 0; i < m * n; i++)
      if (C_golden[i] != C_yours[i]){
          count2++;
          break
      }
  if (count2 == 0)
      printf("GEMM (your method) PASS!\n\n");
  else
      printf("GEMM (your method) NOT PASS!\n\n");
```

That’s all!

End!