Week6 Lab1 Report

111062117, Hsiang-Sheng Huang

April 9, 2025

HPL (High-Performance Linpack)

Setting of N

N is the matrix dimension used in HPL and is the number of rows and columns in the matrix. That is, the matrix is $N \times N$.

N should be 80% $\sim$ 85% of the total memory size, and there is a reference formula:

$$N = \sqrt{\frac{\texttt{Total Memory}}{8}}$$

So first we use the following command to check the total memory size:

```
$ cat /proc/meminfo | grep MemTotal
```

The output is:

```
MemTotal:        3930592 kB
```

Then we can calculate the value of N:

$$\begin{aligned} \texttt{Total Memory} &= 3930592 \text{ kB} \\ N &= \sqrt{\frac{3930592 \times 1024}{8}} \\ &\approx 22450 \end{aligned}$$

This is the value of N assuming all memory is used to store the matrix.

To avoid OOM (Out Of Memory), we set 80% $\sim$ 85% of the total memory size.

- $N = 22450 \times \sqrt{0.8} \approx 20070$
- $N = 22450 \times \sqrt{0.85} \approx 20700$

Also, we would like to set N to a multiple of NB, so we can set N to 20480.

Setting of NB

NB is the block size used in HPL. The block size is the number of rows and columns in the sub-matrix. That is, the sub-matrix is NB $\times$ NB.

NB values in [32 ... 256] can achieve good performance.

Here we set NB to 64.

Setting of P and Q

P and Q are the number of processes in the row and column of the process grid. The product of P and Q should be equal to the number of processes used in HPL.

The number of processes used in HPL is 8, so here we set $P = 2$ and $Q = 4$.

Results

The following image shows the results.

```
The following parameter values will be used:

N      :   20480
NB     :      64
PMAP   : Row-major process mapping
P      :       2
Q      :       4
PFACT  :   Right
NBMIN  :       4
NDIV   :       2
RFACT  :   Crout
BCAST  :  1ringM
DEPTH  :       1
SWAP   : Mix (threshold = 64)
L1     : transposed form
U      : transposed form
EQUIL  : yes
ALIGN  : 8 double precision words

--------------------------------------------------------------------------------

- The matrix A is randomly generated for each test.
- The following scaled residual check will be computed:
      ||Ax-b||_oo / ( eps * ( || x ||_oo * || A ||_oo + || b ||_oo ) * N )
- The relative machine precision (eps) is taken to be               1.110223e-16
- Computational tests pass if scaled residuals are less than                16.0

================================================================================
T/V                N    NB     P     Q               Time                 Gflops
--------------------------------------------------------------------------------
WR11C2R4       20480    64     2     4             267.79             2.1387e+01
HPL_pdgesv() start time Tue Apr  8 18:29:57 2025

HPL_pdgesv() end time   Tue Apr  8 18:34:25 2025

--------------------------------------------------------------------------------
||Ax-b||_oo/(eps*(||A||_oo*||x||_oo+||b||_oo)*N)=   3.76990531e-03 ...... PASSED
================================================================================

Finished      1 tests with the following results:
              1 tests completed and passed residual checks,
              0 tests completed and failed residual checks,
              0 tests skipped because of illegal input values.
--------------------------------------------------------------------------------
```

The image shows PASSED and Gflops is 2.1387e+01. Gflops means the performance of the matrix multiplication. The higher the Gflops, the better the performance.

Results under different parameters

The following image shows the results under different parameters.

(N, NB, P, Q) = (1000, 64, 2, 2)

It is run with the following command:

```
$ mpirun -np 4 ./xhpl
```

The following image shows the results.

```
The following parameter values will be used:

N      :    1000
NB     :      64
PMAP   : Row-major process mapping
P      :       2
Q      :       2
PFACT  :   Right
NBMIN  :       4
NDIV   :       2
RFACT  :   Crout
BCAST  :   1ring
DEPTH  :       0
SWAP   : Mix (threshold = 64)
L1     : transposed form
U      : transposed form
EQUIL  : yes
ALIGN  : 8 double precision words

--------------------------------------------------------------------------------

- The matrix A is randomly generated for each test.
- The following scaled residual check will be computed:
      ||Ax-b||_oo / ( eps * ( || x ||_oo * || A ||_oo + || b ||_oo ) * N )
- The relative machine precision (eps) is taken to be              1.110223e-16
- Computational tests pass if scaled residuals are less than                16.0

================================================================================
T/V                N    NB     P     Q               Time                 Gflops
--------------------------------------------------------------------------------
WR00C2R4        1000    64     2     2               0.08             8.6588e+00
HPL_pdgesv() start time Thu Apr  3 14:03:32 2025

HPL_pdgesv() end time   Thu Apr  3 14:03:32 2025

--------------------------------------------------------------------------------
||Ax-b||_oo/(eps*(||A||_oo*||x||_oo+||b||_oo)*N)=   6.82595333e-03 ...... PASSED
================================================================================

Finished      1 tests with the following results:
              1 tests completed and passed residual checks,
              0 tests completed and failed residual checks,
              0 tests skipped because of illegal input values.
--------------------------------------------------------------------------------
```

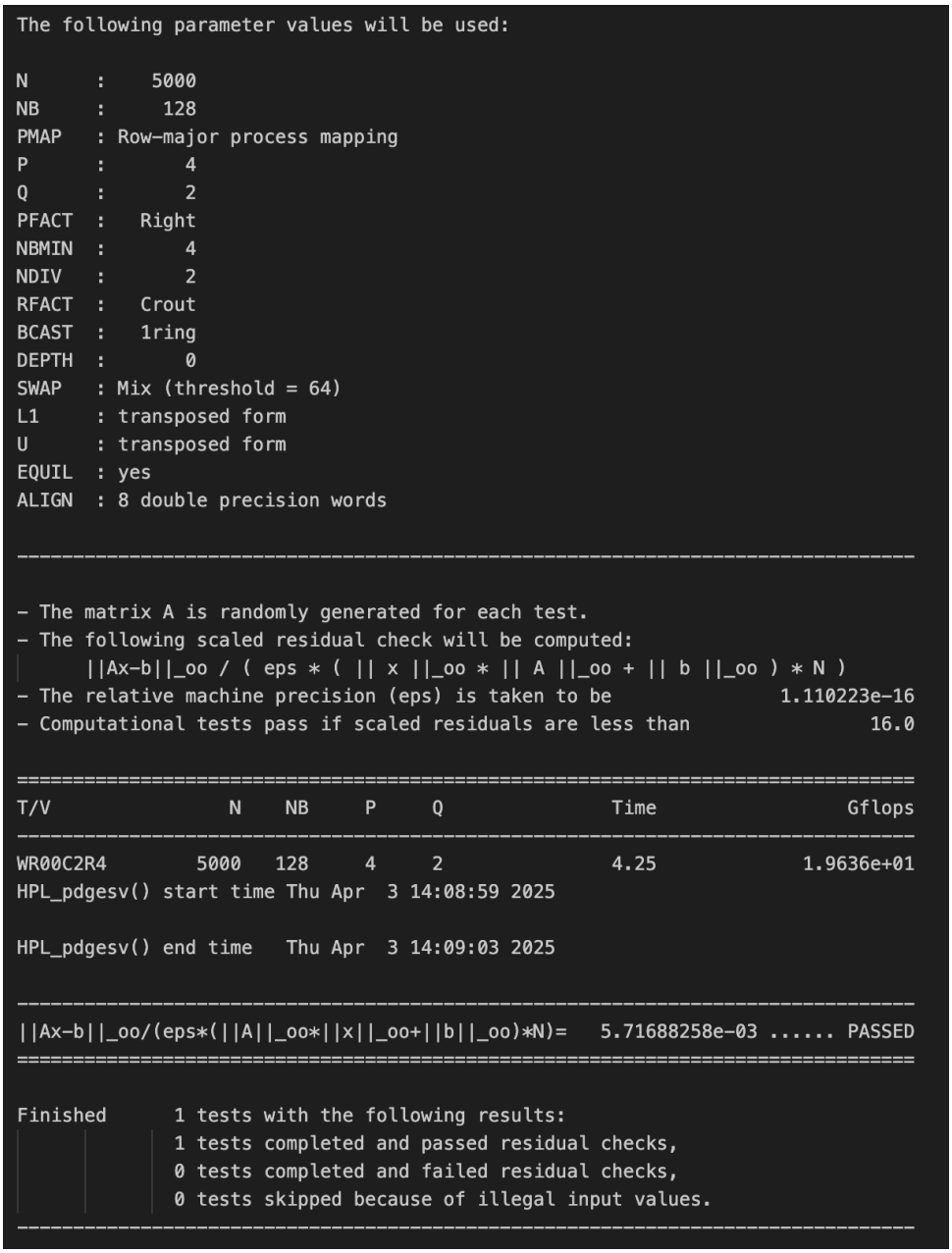
The image shows PASSED and Gflops is 8.6588e+00.

(N, NB, P, Q) = (5000, 128, 4, 2)

It is run with the following command:

```
$ mpirun -np 8 ./xhpl
```

The following image shows the results.



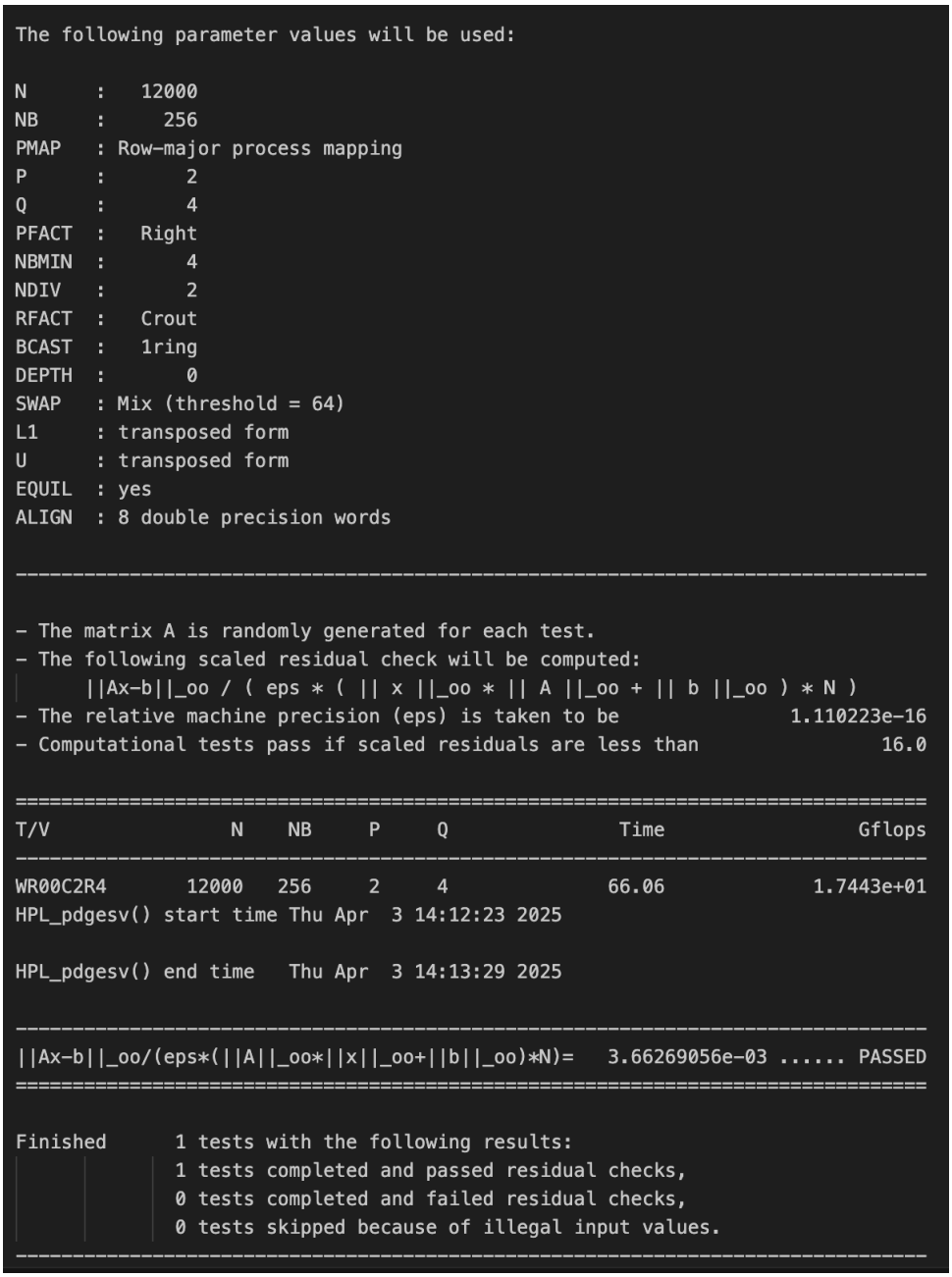
The image shows PASSED and Gflops is 1.9636e+01.

(N, NB, P, Q) = (12000, 256, 2, 4)

It is run with the following command:

```
$ mpirun -np 8 ./xhpl
```

The following image shows the results.



The image shows PASSED and Gflops is 1.7433e+01.

HPCG (High Performance Conjugate Gradient)

Setting of nx, ny, nz

The parameters nx, ny, and nz define the dimensions of the 3D matrix used in HPCG. The matrix has dimensions $nx \times ny \times nz$ with a total of $nx \times ny \times nz$ elements.

I set nx, ny, and nz to 96. and use the following command to run HPCG:

```
$ mpirun -np 8 ./xhpcg
```

This value was determined through testing to be the maximum that avoids OOM errors.

Setting of Time

In HPCG, the time parameter specifies the maximum duration (in seconds) allocated for the benchmark run.

I set the time to 10 seconds. Because the time is too long, it will take a long time to run.

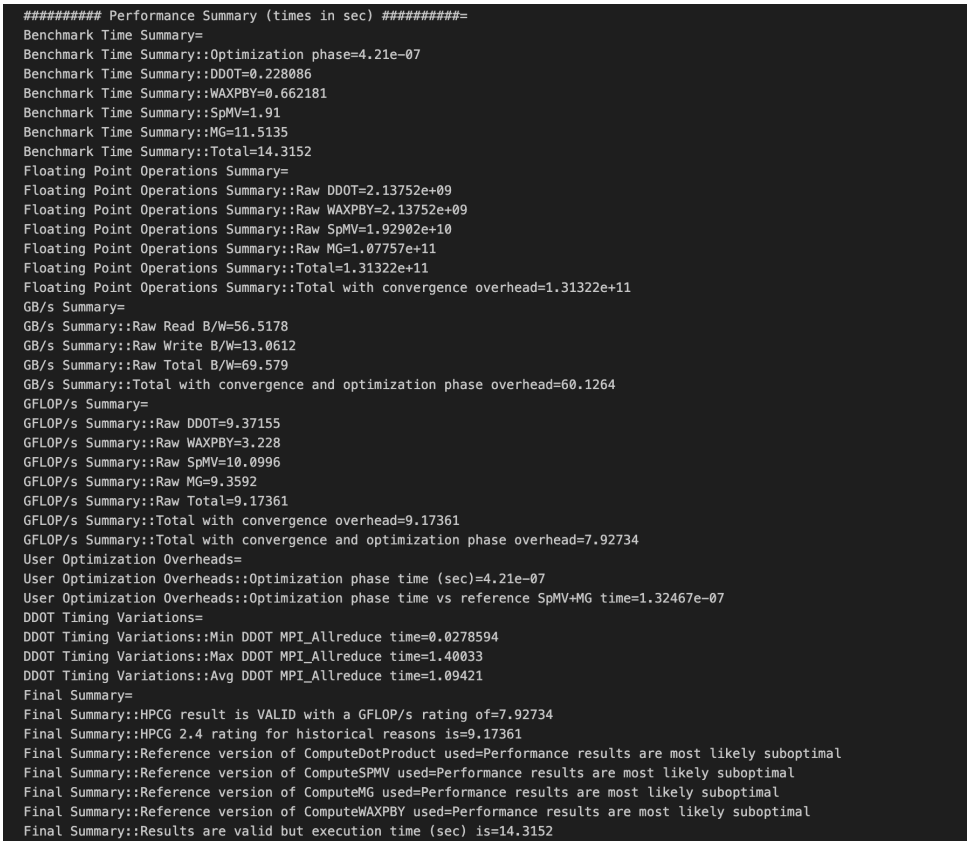
Results

```
Machine Summary=
Machine Summary::Distributed Processes=8
Machine Summary::Threads per processes=1
Global Problem Dimensions=
Global Problem Dimensions::Global nx=192
Global Problem Dimensions::Global ny=192
Global Problem Dimensions::Global nz=192
Processor Dimensions=
Processor Dimensions::npx=2
Processor Dimensions::npy=2
Processor Dimensions::npz=2
```

The image shows that it is actually decomposed into a $2 \times 2 \times 2$ grid across three dimensions. In effect, the matrix being processed is $(96 \times 2) \times (96 \times 2) \times (96 \times 2)$.

```
########## Memory Use Summary  ##########=
Memory Use Information=
Memory Use Information::Total memory used for data (Gbytes)=5.06338
Memory Use Information::Memory used for OptimizeProblem data (Gbytes)=0
Memory Use Information::Bytes per equation (Total memory / Number of Equations)=715.379
Memory Use Information::Memory used for linear system and CG (Gbytes)=4.45557
Memory Use Information::Coarse Grids=
Memory Use Information::Coarse Grids::Grid Level=1
Memory Use Information::Coarse Grids::Memory used=0.532715
Memory Use Information::Coarse Grids::Grid Level=2
Memory Use Information::Coarse Grids::Memory used=0.0667185
Memory Use Information::Coarse Grids::Grid Level=3
Memory Use Information::Coarse Grids::Memory used=0.00837444
```

The memory usage is reported as 5.06338 GB. Although this exceeds the memory size, it is likely that swap space or system memory management is compensating.



The image shows HPCG result is VALID with a GFLOP/s rating of=7.92734.

Results under different parameters

(nx, ny, nz) = (56, 56, 56)

It is run with the following command:

```
$ mpirun -np 8 ./xhpcg
```

```
########## Performance Summary (times in sec) ##########=
Benchmark Time Summary=
Benchmark Time Summary::Optimization phase=3.41e-07
Benchmark Time Summary::DDOT=1.24377
Benchmark Time Summary::WAXPBY=0.101233
Benchmark Time Summary::SpMV=1.37798
Benchmark Time Summary::MG=8.81858
Benchmark Time Summary::Total=11.5423
Floating Point Operations Summary=
Floating Point Operations Summary::Raw DDOT=1.69715e+09
Floating Point Operations Summary::Raw WAXPBY=1.69715e+09
Floating Point Operations Summary::Raw SpMV=1.5202e+10
Floating Point Operations Summary::Raw MG=8.48219e+10
Floating Point Operations Summary::Total=1.03418e+11
Floating Point Operations Summary::Total with convergence overhead=1.03418e+11
GB/s Summary=
GB/s Summary::Raw Read B/W=55.2131
GB/s Summary::Raw Write B/W=12.7603
GB/s Summary::Raw Total B/W=67.9734
GB/s Summary::Total with convergence and optimization phase overhead=66.7036
GFLOP/s Summary=
GFLOP/s Summary::Raw DDOT=1.36453
GFLOP/s Summary::Raw WAXPBY=16.7648
GFLOP/s Summary::Raw SpMV=11.0321
GFLOP/s Summary::Raw MG=9.61855
GFLOP/s Summary::Raw Total=8.95992
GFLOP/s Summary::Total with convergence overhead=8.95992
GFLOP/s Summary::Total with convergence and optimization phase overhead=8.79255
User Optimization Overheads=
User Optimization Overheads::Optimization phase time (sec)=3.41e-07
User Optimization Overheads::Optimization phase time vs reference SpMV+MG time=4.81003e-06
DDOT Timing Variations=
DDOT Timing Variations::Min DDOT MPI_Allreduce time=0.437113
DDOT Timing Variations::Max DDOT MPI_Allreduce time=1.64498
DDOT Timing Variations::Avg DDOT MPI_Allreduce time=1.00263
Final Summary=
Final Summary::HPCG result is VALID with a GFLOP/s rating of=8.79255
Final Summary::HPCG 2.4 rating for historical reasons is=8.95992
Final Summary::Reference version of ComputeDotProduct used=Performance results are most likely suboptimal
Final Summary::Reference version of ComputeSPMV used=Performance results are most likely suboptimal
Final Summary::Reference version of ComputeMG used=Performance results are most likely suboptimal
Final Summary::Reference version of ComputeWAXPBY used=Performance results are most likely suboptimal
Final Summary::Results are valid but execution time (sec) is=11.5423
```

The image shows HPCG result is VALID with a GFLOP/s rating of=8.79255.

(nx, ny, nz) = (64, 64, 64)

It is run with the following command:

```
$ mpirun -np 8 ./xhpcg
```

```
########## Performance Summary (times in sec) ##########=
Benchmark Time Summary=
Benchmark Time Summary::Optimization phase=6.82e-07
Benchmark Time Summary::DDOT=0.725828
Benchmark Time Summary::WAXPBY=0.10851
Benchmark Time Summary::SpMV=1.2419
Benchmark Time Summary::MG=7.84544
Benchmark Time Summary::Total=9.92222
Floating Point Operations Summary=
Floating Point Operations Summary::Raw DDOT=1.26668e+09
Floating Point Operations Summary::Raw WAXPBY=1.26668e+09
Floating Point Operations Summary::Raw SpMV=1.13716e+10
Floating Point Operations Summary::Raw MG=6.34715e+10
Floating Point Operations Summary::Total=7.73764e+10
Floating Point Operations Summary::Total with convergence overhead=7.73764e+10
GB/s Summary=
GB/s Summary::Raw Read B/W=48.0518
GB/s Summary::Raw Write B/W=11.1051
GB/s Summary::Raw Total B/W=59.1569
GB/s Summary::Total with convergence and optimization phase overhead=54.8632
GFLOP/s Summary=
GFLOP/s Summary::Raw DDOT=1.74515
GFLOP/s Summary::Raw WAXPBY=11.6734
GFLOP/s Summary::Raw SpMV=9.15661
GFLOP/s Summary::Raw MG=8.09023
GFLOP/s Summary::Raw Total=7.79829
GFLOP/s Summary::Total with convergence overhead=7.79829
GFLOP/s Summary::Total with convergence and optimization phase overhead=7.23228
User Optimization Overheads=
User Optimization Overheads::Optimization phase time (sec)=6.82e-07
User Optimization Overheads::Optimization phase time vs reference SpMV+MG time=3.82261e-06
DDOT Timing Variations=
DDOT Timing Variations::Min DDOT MPI_Allreduce time=0.243849
DDOT Timing Variations::Max DDOT MPI_Allreduce time=1.1776
DDOT Timing Variations::Avg DDOT MPI_Allreduce time=0.659975
Final Summary=
Final Summary::HPCG result is VALID with a GFLOP/s rating of=7.23228
Final Summary::HPCG 2.4 rating for historical reasons is=7.79829
Final Summary::Reference version of ComputeDotProduct used=Performance results are most likely suboptimal
Final Summary::Reference version of ComputeSPMV used=Performance results are most likely suboptimal
Final Summary::Reference version of ComputeMG used=Performance results are most likely suboptimal
Final Summary::Reference version of ComputeWAXPBY used=Performance results are most likely suboptimal
Final Summary::Results are valid but execution time (sec) is=9.92222
```

The image shows HPCG result is VALID with a GFLOP/s rating of=7.23228.