

HPC 高性能计算项目

Linpack 性能测试报告



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1 Linpack 简介

Linpack 是国际上最流行的用于测试高性能计算机系统浮点性能的 benchmark。通过对高性能计算机采用高斯消元法求解一元 N 次稠密线性代数方程组的测试, 评价高性能计算机的浮点性能。

Linpack 测试包括三类, Linpack100、Linpack1000 和 HPL。Linpack100 求解规模为 100 阶的稠密线性代数方程组, 它只允许采用编译优化选项进行优化, 不得更改代码, 甚至代码中的注释也不得修改。Linpack1000 要求求解 1000 阶的线性代数方程组, 达到指定的精度要求, 可以在不改变计算量的前提下做算法和代码上做优化。HPL 即 High Performance Linpack, 也叫高度并行计算基准测试, 它对数组大小 N 没有限制, 求解问题的规模可以改变, 除基本算法(计算量)不可改变外, 可以采用其它任何优化方法。前两种测试运行规模较小, 已不是很适合现代计算机的发展。

HPL 是针对现代并行计算机提出的测试方式。用户在不修改任意测试程序的基础上, 可以调节问题规模大小(矩阵大小)、使用 CPU 数目、使用各种优化方法等等来执行该测试程序, 以获取最佳的性能。HPL 采用高斯消元法求解线性方程组。求解问题规模为 N 时, 浮点运算次数为 $(\frac{2}{3} * N^3 - 2 * N^2)$ 。因此, 只要给出问题规模 N , 测得系统计算时间 T , 峰值 = 计算量 $(\frac{2}{3} * N^3 - 2 * N^2)$ / 计算时间 T , 测试结果以浮点运算每秒 (Flops) 给出。HPL 测试结果是 TOP500 排名的重要依据。

衡量计算机性能的一个重要指标就是计算峰值或者浮点计算峰值, 它是指计算机每秒钟能完成的浮点计算最大次数。包括理论浮点峰值和实测浮点峰值。理论浮点峰值是该计算机理论上能达到的每秒钟能完成浮点计算最大次数, 它主要是由 CPU 的主频决定的。

理论浮点峰值 = CPU 主频 $\times$ CPU 每个时钟周期执行浮点运算的次数 $\times$ 系统中 CPU 数。

2 HPC 集群测试环境

注释：报告完成后请删除
1、请根据硬件配置实际情况修改；

测试集群为某项目部署的 60 个刀片计算节点，主机名为 comput1 到 comput60，集群内部管理网 IP 地址为 192.168.172.1-60，集群计算网 IP 地址为 12.12.12.1-60，详情请参考各节点的/etc/hosts 文件。登录方式为，从集群管理节点 login 登录，可 ssh 到各计算节点。

集群软硬件环境如下：

硬件环境	CPU	2*Intel Xeon E5-2680 v3 (2.5GHz) 12c
	内存	8*8GB DDR4 ECC
	硬盘	双硬盘
	网络	Infiniband FDR 56Gbps
软件环境	OS	CentOS release 6.6 (Final)
	编译器	Intel Compiler XE Version 15.0 Build 20150121
	MPI	OpenMPI-1.8.5
	HPL	2.1

单节点 Linpack 双精度浮点计算理论峰值计算数值为：

$$2.5 \text{ (主频 GHz)} * 16 \text{ (每时钟周期运算次数)} * 24 \text{(核心/节点)} = 960 \text{ GFlops}$$

集群整机 Linpack 双精度浮点计算理论峰值计算数值为：

$$2.5 \text{ (主频 GHz)} * 16 \text{ (每时钟周期运算次数)} * 24 \text{(核心/节点)} * 60 \text{ (节点数量)} = 576000$$

$$\text{GFlops} = 576 \text{ TFlops}$$

3 单机 Linpack 测试

注释：报告完成后请删除

- 1、需要预先安装曙光 Clussoft 中的 benchmark 工具集，参考【Clussoft 使用手册】中的 clusbench 工具，进行自动化单机和整机 Linpack 测试
- 2、也可以进行手动运行调优测试
- 3、HPL.dat 参数修改详见附录 5.1

3.1 测试方案

2.1.1 测试对象：

HPC 集群所有 60 个刀片计算节点

2.1.2 测试目标：

- 1.检验所有节点是否能正常运行、是否存在软硬件异常；
- 2.检验各刀片计算节点的计算效率是否正常；
- 3.检验各刀片计算节点在长时间持续高负载运行时，性能是否正常且稳定；
- 4.检验各刀片计算节点在长时间持续高负载运行时，温度和散热是否正常；
- 5.检验各刀片计算节点在长时间持续高负载运行时，供电是否正常稳定；

2.1.3 测试步骤：

1) 进行测试之前，需要确保整个集群环境正常。所有节点正常，且无负载，调试好 Infiniband 网络，确保风扇正常、CPU 温度无异常，确保测试相关的环境变量已导入，无异常进程和服务。

2) 随机选取任一计算节点，通过不断调整和优化相关测试参数，测得单机 Linpack 效率较高时的运行参数。

3) 使用在 2) 中获取的运行参数，同时对各节点进行单机 Linpack 测试。

4) 建立测试目录，将输入文件 HPL.dat 和测试程序 xhpl 拷到本目录下，手动运行单机

Linpac 测试命令：

```
nohup mpirun -np 24 /public/software/benchmark/hpl/2.1/intel/xhpl.Linux_Intel64 >&
`hostname`_single.log &
```

3.2 测试结果

单机 (NB=168)									
主机名	节点数	CPU核心数	理论峰值 (Gflops)	实测峰值 (Gflops)	效率	N	NB	P	Q
node1	1	24	960	6.82E+02	71.0%	79897	168	4	6
node2	1	24	960	7.18E+02	74.8%	79897	168	4	6
node3	1	24	960	7.10E+02	74.0%	79897	168	4	6
node4	1	24	960	6.98E+02	72.7%	79897	168	4	6
node5	1	24	960	6.78E+02	70.6%	79897	168	4	6
node6	1	24	960	6.88E+02	71.7%	79897	168	4	6
node7	1	24	960	6.74E+02	70.2%	79897	168	4	6
node8	1	24	960	6.88E+02	71.7%	79897	168	4	6
node9	1	24	960	6.79E+02	70.7%	79897	168	4	6
node10	1	24	960	6.97E+02	72.6%	79897	168	4	6
node11	1	24	960	6.98E+02	72.7%	79897	168	4	6
node12	1	24	960	6.96E+02	72.5%	79897	168	4	6
node13	1	24	960	6.88E+02	71.6%	79897	168	4	6
node14	1	24	960	7.27E+02	75.8%	79897	168	4	6
node15	1	24	960	6.83E+02	71.1%	79897	168	4	6
node16	1	24	960	6.88E+02	71.6%	79897	168	4	6
node17	1	24	960	6.85E+02	71.4%	79897	168	4	6
node18	1	24	960	6.86E+02	71.4%	79897	168	4	6
node19	1	24	960	7.19E+02	74.9%	79897	168	4	6
node20	1	24	960	6.82E+02	71.0%	79897	168	4	6
node21	1	24	960	6.84E+02	71.3%	79897	168	4	6
node22	1	24	960	7.10E+02	74.0%	79897	168	4	6
node23	1	24	960	6.85E+02	71.4%	79897	168	4	6
node24	1	24	960	6.83E+02	71.2%	79897	168	4	6
node25	1	24	960	7.16E+02	74.6%	79897	168	4	6
node26	1	24	960	6.86E+02	71.4%	79897	168	4	6
node27	1	24	960	7.19E+02	74.9%	79897	168	4	6
node28	1	24	960	6.87E+02	71.6%	79897	168	4	6

node29	1	24	960	6.92E+02	72.0%	79897	168	4	6
node30	1	24	960	6.82E+02	71.0%	79897	168	4	6
node31	1	24	960	6.89E+02	71.8%	79897	168	4	6
node32	1	24	960	6.83E+02	71.2%	79897	168	4	6
node33	1	24	960	7.18E+02	74.8%	79897	168	4	6
node34	1	24	960	6.88E+02	71.6%	79897	168	4	6
node35	1	24	960	6.82E+02	71.0%	79897	168	4	6
node36	1	24	960	7.18E+02	74.8%	79897	168	4	6
node37	1	24	960	7.10E+02	73.9%	79897	168	4	6
node38	1	24	960	6.93E+02	72.2%	79897	168	4	6
node39	1	24	960	7.18E+02	74.8%	79897	168	4	6
node40	1	24	960	7.18E+02	74.8%	79897	168	4	6
node41	1	24	960	7.15E+02	74.5%	79897	168	4	6
node42	1	24	960	6.88E+02	71.7%	79897	168	4	6
node43	1	24	960	6.98E+02	72.7%	79897	168	4	6
node44	1	24	960	7.27E+02	75.7%	79897	168	4	6
node45	1	24	960	7.22E+02	75.2%	79897	168	4	6
node46	1	24	960	6.85E+02	71.3%	79897	168	4	6
node47	1	24	960	7.02E+02	73.1%	79897	168	4	6
node48	1	24	960	6.84E+02	71.3%	79897	168	4	6
node49	1	24	960	6.89E+02	71.8%	79897	168	4	6
node50	1	24	960	6.96E+02	72.5%	79897	168	4	6
node51	1	24	960	6.86E+02	71.4%	79897	168	4	6
node52	1	24	960	7.07E+02	73.7%	79897	168	4	6
node53	1	24	960	7.15E+02	74.5%	79897	168	4	6
node54	1	24	960	6.91E+02	72.0%	79897	168	4	6
node55	1	24	960	7.18E+02	74.8%	79897	168	4	6
node56	1	24	960	7.06E+02	73.5%	79897	168	4	6
node57	1	24	960	6.75E+02	70.5%	79897	168	4	6
node58	1	24	960	6.87E+02	71.5%	79897	168	4	6
node59	1	24	960	7.19E+02	74.9%	79897	168	4	6
node60	1	24	960	6.93E+02	72.2%	79897	168	4	6
均值					72.7%				

3.3 结果分析

如上表所示，实测单机 Linpack 效率最高为 75.8%，最低为 70.2%，60 个计算节点的单机效率平均值是 72.7% (NB=168)。各节点运行效率正常，且表现稳定。

4 整机 Linpack 测试

4.1 测试方案

3.1.1 测试对象：

HPC 集群所有 60 个正常的节点

3.1.2 测试目标：

- 1.检验所有节点是否能正常运行、是否存在软硬件异常；
- 2.检验并行环境及计算网络的状态是否正常；
- 3.检验集群计算效率是否正常；
- 4.检验集群在长时间持续高负载运行时，性能是否正常且稳定；
- 5.检验集群在长时间持续高负载运行时，温度和散热否正常；
- 6.检验集群在长时间持续高负载运行时，供电是否能正常；

3.1.3 测试步骤：

1) .进行测试之前，需要确保整个集群环境正常。所有节点正常，且无负载，调试好 Infiniband 网络，确保风扇正常，CPU 温度无异常，确保测试相关的环境变量已导入，无异常进程和服务。

2) . 通过不断调整和优化相关测试参数，测得整机 Linpack 效率较高时的运行参数和结果数据。

3) 根据 2)参数进行 24 小时压力测试。

4) 建立测试目录，将输入文件 HPL.dat 和测试程序 xhpl 拷到本目录下，手动运行整机

Linpack 测试命令：

```
nohup mpirun -np 1440 -machinefile nodelist  
/public/software/benchmark/hpl/2.1/intel/xhpl.Linux_Intel64 >& total_nodes.log &
```

4.2 测试结果

60 节点整机 Linpack								
节点数	CPU 核 心数	理论峰值 (Gflops)	实测峰值 (Gflops)	效率	N	NB	P	Q
60	1440	57600	4.122e+03	71.50%	622119	168	36	40
60	1440	57600	4.159e+03	72.27%	622119	168	36	40
60	1440	57600	4.019e+03	69.77%	622119	168	36	40
60	1440	57600	4.141e+03	71.89%	622119	168	36	40

4.3 结果分析

60 节点的整机 Linpack 效率为 72.3%，计算性能表现稳定良好，测试期间，集群整体运行状态正常稳定，电源、风扇及功耗等硬件监控情况稳定无异常。

5 附录

5.1 HPL.dat 修改说明

HPL 输入文件内容如下，一般需要调整三部分参数进行优化测试：

1) 问题规模的个数及大小，可设置为多组，N=1 表示一组，需要一个 Ns 值。问题规

模计算方法为 $\text{sqrt}(\text{总内存} * 1024 * 1024 * 1024 / 8) * 80\%$

1	# of problems sizes (N)
40000	Ns

2) NB 值，即分块大小，取经验值，一般设置 168、192、232、1024

3	# of NBs
192 232 1024	NBs

3) P 和 Q 的设置（进程数目的设置），P 和 Q 设置一般为 1 组，原则为：

$P * Q = \text{进程数}$

$P \leq Q$ 且 P 和 Q 尽量接近

例如 16 进程， $P=Q=4$ ，如 32 进程， $P=4$ ， $Q=8$

1	# of process grids (P×Q)
4	Ps
4	Qs

修改好的 HPL.dat 示例 (红色为修改项):

```
HPLinpack benchmark input file
Innovative Computing Laboratory, University of Tennessee
HPL.out      output file name (if any)
6            device out (6=stdout,7=stderr,file)
1            # of problems sizes (N)
79897        # = sqrt (总内存 * 1024 * 1024 * 1024 / 8) * 80%  Ns
1            # of NBs
168 192      # NBs
0            PMAP process mapping (0=Row-,1=Column-major)
1            * # of process grids (P x Q)
4            Ps
6            Qs
16.0         threshold
1            # of panel fact
0 1 2        PFACTs (0=left, 1=Crout, 2=Right)
1            # of recursive stopping criterium
2 4          NBMINs (>= 1)
1            # of panels in recursion
2            NDIVs
1            # of recursive panel fact.
0 1 2        RFACTs (0=left, 1=Crout, 2=Right)
1            # of broadcast
0            BCASTs (0=1rg,1=1rM,2=2rg,3=2rM,4=Lng,5=LnM)
1            # of lookahead depth
0            DEPTHs (>=0)
2            SWAP (0=bin-exch,1=long,2=mix)
64           swapping threshold
0            L1 in (0=transposed,1=no-transposed) form
0            U   in (0=transposed,1=no-transposed) form
1            Equilibration (0=no,1=yes)
8            memory alignment in double (> 0)
```

5.2 附录 1 单机测试原始输入文件

```
HPLinpack benchmark input file
Innovative Computing Laboratory, University of Tennessee
HPL.out      output file name (if any)
6            device out (6=stdout,7=stderr,file)
1            # of problems sizes (N)
79897 108800 108160 107520 106240 104960      1130240   Ns
2            # of NBs
168   192      448 384          NBs
0            PMAP process mapping (0=Row-,1=Column-major)
1            # of process grids (P x Q)
4 1 4        Ps
6 4 1        Qs
16.0         threshold
1            # of panel fact
0 1 2        PFACTs (0=left, 1=Crout, 2=Right)
2            # of recursive stopping criterium
2 4          NBMINs (>= 1)
1            # of panels in recursion
2            NDIVs
3            # of recursive panel fact.
0 1 2        RFACTs (0=left, 1=Crout, 2=Right)
1            # of broadcast
0            BCASTs (0=1rg,1=1rM,2=2rg,3=2rM,4=Lng,5=LnM)
1            # of lookahead depth
0            DEPTHS (>=0)
2            SWAP (0=bin-exch,1=long,2=mix)
64           swapping threshold
0            L1 in (0=transposed,1=no-transposed) form
0            U   in (0=transposed,1=no-transposed) form
1            Equilibration (0=no,1=yes)
8            memory alignment in double (> 0)
```

5.3 附录 2 单机测试输出文件

随机选取一个计算节点输出，本报告以 comput57 节点为例的单机测试的原始输出文件：

```
=====
HPLinpack 2.1  --  High-Performance Linpack benchmark  --  October 26, 2012
Written by A. Petitet and R. Clint Whaley,  Innovative Computing Laboratory, UTK
Modified by Piotr Luszczek, Innovative Computing Laboratory, UTK
Modified by Julien Langou, University of Colorado Denver
=====
```

An explanation of the input/output parameters follows:

```
T/V      : Wall time / encoded variant.
N        : The order of the coefficient matrix A.
NB       : The partitioning blocking factor.
P        : The number of process rows.
Q        : The number of process columns.
Time     : Time in seconds to solve the linear system.
Gflops   : Rate of execution for solving the linear system.
```

The following parameter values will be used:

```
N      :    79897
NB     :     192
PMAP   : Row-major process mapping
P      :       4
Q      :       6
PFACT  : Left
NBMIN  :       2
NDIV   :       2
RFACT  : Left
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:
```

- The relative machine precision (eps) is taken to be 2.220446e-16
- Computational tests pass if scaled residuals are less than 16.0

Begin

|               |         |              |        |        |             |      |            |
|---------------|---------|--------------|--------|--------|-------------|------|------------|
| The progress: | 1.00%.  | Time passed: | 8 s.   | Flops: | 6.0989E+02. | Eff: | 63.530189% |
| The progress: | 2.00%.  | Time passed: | 12 s.  | Flops: | 6.0842E+02. | Eff: | 63.377399% |
| The progress: | 3.00%.  | Time passed: | 19 s.  | Flops: | 6.3736E+02. | Eff: | 66.392166% |
| The progress: | 4.00%.  | Time passed: | 22 s.  | Flops: | 6.5895E+02. | Eff: | 68.640552% |
| The progress: | 5.00%.  | Time passed: | 29 s.  | Flops: | 6.6331E+02. | Eff: | 69.094775% |
| The progress: | 6.00%.  | Time passed: | 32 s.  | Flops: | 6.7463E+02. | Eff: | 70.274053% |
| The progress: | 7.00%.  | Time passed: | 35 s.  | Flops: | 6.8368E+02. | Eff: | 71.216864% |
| The progress: | 8.00%.  | Time passed: | 42 s.  | Flops: | 6.8038E+02. | Eff: | 70.872406% |
| The progress: | 9.00%.  | Time passed: | 45 s.  | Flops: | 6.8627E+02. | Eff: | 71.486160% |
| The progress: | 10.00%. | Time passed: | 52 s.  | Flops: | 6.8193E+02. | Eff: | 71.034343% |
| The progress: | 11.00%. | Time passed: | 55 s.  | Flops: | 6.8604E+02. | Eff: | 71.462985% |
| The progress: | 12.00%. | Time passed: | 62 s.  | Flops: | 6.8133E+02. | Eff: | 70.972318% |
| The progress: | 13.00%. | Time passed: | 65 s.  | Flops: | 6.8432E+02. | Eff: | 71.283550% |
| The progress: | 14.00%. | Time passed: | 71 s.  | Flops: | 6.8907E+02. | Eff: | 71.777666% |
| The progress: | 15.00%. | Time passed: | 74 s.  | Flops: | 6.9092E+02. | Eff: | 71.971035% |
| The progress: | 16.00%. | Time passed: | 81 s.  | Flops: | 6.8523E+02. | Eff: | 71.378483% |
| The progress: | 17.00%. | Time passed: | 87 s.  | Flops: | 6.8776E+02. | Eff: | 71.641746% |
| The progress: | 18.00%. | Time passed: | 90 s.  | Flops: | 6.8871E+02. | Eff: | 71.741022% |
| The progress: | 19.00%. | Time passed: | 96 s.  | Flops: | 6.9010E+02. | Eff: | 71.885127% |
| The progress: | 20.00%. | Time passed: | 99 s.  | Flops: | 6.9056E+02. | Eff: | 71.933317% |
| The progress: | 21.00%. | Time passed: | 105 s. | Flops: | 6.9109E+02. | Eff: | 71.988926% |
| The progress: | 22.00%. | Time passed: | 111 s. | Flops: | 6.9118E+02. | Eff: | 71.997700% |
| The progress: | 23.00%. | Time passed: | 114 s. | Flops: | 6.9107E+02. | Eff: | 71.986899% |
| The progress: | 24.00%. | Time passed: | 120 s. | Flops: | 6.9061E+02. | Eff: | 71.938842% |
| The progress: | 25.00%. | Time passed: | 126 s. | Flops: | 6.8985E+02. | Eff: | 71.859867% |
| The progress: | 26.00%. | Time passed: | 129 s. | Flops: | 6.8938E+02. | Eff: | 71.810190% |
| The progress: | 27.00%. | Time passed: | 135 s. | Flops: | 6.8825E+02. | Eff: | 71.692831% |
| The progress: | 28.00%. | Time passed: | 141 s. | Flops: | 6.8692E+02. | Eff: | 71.554158% |
| The progress: | 29.00%. | Time passed: | 144 s. | Flops: | 6.8619E+02. | Eff: | 71.477714% |
| The progress: | 30.00%. | Time passed: | 149 s. | Flops: | 6.8919E+02. | Eff: | 71.790732% |
| The progress: | 31.00%. | Time passed: | 155 s. | Flops: | 6.8727E+02. | Eff: | 71.590276% |
| The progress: | 32.00%. | Time passed: | 160 s. | Flops: | 6.8951E+02. | Eff: | 71.823973% |
| The progress: | 33.00%. | Time passed: | 166 s. | Flops: | 6.8720E+02. | Eff: | 71.583562% |
| The progress: | 34.00%. | Time passed: | 168 s. | Flops: | 6.9010E+02. | Eff: | 71.885602% |
| The progress: | 35.00%. | Time passed: | 174 s. | Flops: | 6.8753E+02. | Eff: | 71.617242% |
| The progress: | 36.00%. | Time passed: | 179 s. | Flops: | 6.8872E+02. | Eff: | 71.741735% |
| The progress: | 37.00%. | Time passed: | 184 s. | Flops: | 6.8963E+02. | Eff: | 71.836502% |
| The progress: | 38.00%. | Time passed: | 190 s. | Flops: | 6.8665E+02. | Eff: | 71.525585% |
| The progress: | 39.00%. | Time passed: | 195 s. | Flops: | 6.8714E+02. | Eff: | 71.577581% |

|                                                                             |
|-----------------------------------------------------------------------------|
| The progress: 40.00%. Time passed: 200 s. Flops: 6.8742E+02. Eff:71.606208% |
| The progress: 41.00%. Time passed: 205 s. Flops: 6.8749E+02. Eff:71.613290% |
| The progress: 42.00%. Time passed: 210 s. Flops: 6.8736E+02. Eff:71.600479% |
| The progress: 43.00%. Time passed: 215 s. Flops: 6.8707E+02. Eff:71.569272% |
| The progress: 44.00%. Time passed: 220 s. Flops: 6.8660E+02. Eff:71.521031% |
| The progress: 45.00%. Time passed: 225 s. Flops: 6.8599E+02. Eff:71.456997% |
| The progress: 46.00%. Time passed: 229 s. Flops: 6.8822E+02. Eff:71.689997% |
| The progress: 47.00%. Time passed: 234 s. Flops: 6.8727E+02. Eff:71.590622% |
| The progress: 48.00%. Time passed: 239 s. Flops: 6.8620E+02. Eff:71.478814% |
| The progress: 49.00%. Time passed: 243 s. Flops: 6.8783E+02. Eff:71.649078% |
| The progress: 50.00%. Time passed: 250 s. Flops: 6.8714E+02. Eff:71.577285% |
| The progress: 51.00%. Time passed: 255 s. Flops: 6.8562E+02. Eff:71.419058% |
| The progress: 52.00%. Time passed: 259 s. Flops: 6.8666E+02. Eff:71.527179% |
| The progress: 53.00%. Time passed: 263 s. Flops: 6.8753E+02. Eff:71.617428% |
| The progress: 54.00%. Time passed: 270 s. Flops: 6.8597E+02. Eff:71.455592% |
| The progress: 55.00%. Time passed: 274 s. Flops: 6.8648E+02. Eff:71.508645% |
| The progress: 56.00%. Time passed: 278 s. Flops: 6.8685E+02. Eff:71.546671% |
| The progress: 57.00%. Time passed: 284 s. Flops: 6.8714E+02. Eff:71.577107% |
| The progress: 58.00%. Time passed: 288 s. Flops: 6.8717E+02. Eff:71.580644% |
| The progress: 59.00%. Time passed: 294 s. Flops: 6.8700E+02. Eff:71.562386% |
| The progress: 60.00%. Time passed: 298 s. Flops: 6.8674E+02. Eff:71.535359% |
| The progress: 61.00%. Time passed: 304 s. Flops: 6.8615E+02. Eff:71.473903% |
| The progress: 62.00%. Time passed: 308 s. Flops: 6.8563E+02. Eff:71.419733% |
| The progress: 63.00%. Time passed: 313 s. Flops: 6.8686E+02. Eff:71.547738% |
| The progress: 64.00%. Time passed: 319 s. Flops: 6.8565E+02. Eff:71.422234% |
| The progress: 65.00%. Time passed: 324 s. Flops: 6.8637E+02. Eff:71.497254% |
| The progress: 66.00%. Time passed: 328 s. Flops: 6.8532E+02. Eff:71.387426% |
| The progress: 67.00%. Time passed: 333 s. Flops: 6.8565E+02. Eff:71.422265% |
| The progress: 68.00%. Time passed: 338 s. Flops: 6.8576E+02. Eff:71.433526% |
| The progress: 69.00%. Time passed: 343 s. Flops: 6.8566E+02. Eff:71.422471% |
| The progress: 70.00%. Time passed: 348 s. Flops: 6.8535E+02. Eff:71.390292% |
| The progress: 71.00%. Time passed: 355 s. Flops: 6.8400E+02. Eff:71.249495% |
| The progress: 72.00%. Time passed: 359 s. Flops: 6.8517E+02. Eff:71.371541% |
| The progress: 73.00%. Time passed: 364 s. Flops: 6.8424E+02. Eff:71.274724% |
| The progress: 74.00%. Time passed: 368 s. Flops: 6.8500E+02. Eff:71.354616% |
| The progress: 75.00%. Time passed: 374 s. Flops: 6.8450E+02. Eff:71.301867% |
| The progress: 76.00%. Time passed: 378 s. Flops: 6.8483E+02. Eff:71.336247% |
| The progress: 77.00%. Time passed: 384 s. Flops: 6.8380E+02. Eff:71.229326% |
| The progress: 78.00%. Time passed: 389 s. Flops: 6.8427E+02. Eff:71.277711% |
| The progress: 79.00%. Time passed: 394 s. Flops: 6.8443E+02. Eff:71.294912% |
| The progress: 80.00%. Time passed: 399 s. Flops: 6.8431E+02. Eff:71.282574% |
| The progress: 81.00%. Time passed: 404 s. Flops: 6.8393E+02. Eff:71.242261% |
| The progress: 82.00%. Time passed: 409 s. Flops: 6.8328E+02. Eff:71.175460% |

The progress: 83.00%. Time passed: 415 s. Flops: 6.8256E+02. Eff:71.099666%

The progress: 84.00%. Time passed: 419 s. Flops: 6.8301E+02. Eff:71.147157%

The progress: 85.00%. Time passed: 424 s. Flops: 6.8323E+02. Eff:71.170080%

The progress: 86.00%. Time passed: 430 s. Flops: 6.8150E+02. Eff:70.989161%

The progress: 87.00%. Time passed: 434 s. Flops: 6.8259E+02. Eff:71.103002%

The progress: 88.00%. Time passed: 440 s. Flops: 6.8156E+02. Eff:70.996185%

The progress: 89.00%. Time passed: 445 s. Flops: 6.8163E+02. Eff:71.002848%

The progress: 90.00%. Time passed: 450 s. Flops: 6.8124E+02. Eff:70.962617%

The progress: 91.00%. Time passed: 455 s. Flops: 6.8151E+02. Eff:70.990116%

The progress: 92.00%. Time passed: 460 s. Flops: 6.8121E+02. Eff:70.958859%

The progress: 93.00%. Time passed: 466 s. Flops: 6.7980E+02. Eff:70.812959%

The progress: 94.00%. Time passed: 471 s. Flops: 6.8001E+02. Eff:70.834427%

The progress: 95.00%. Time passed: 476 s. Flops: 6.8012E+02. Eff:70.845807%

The progress: 96.00%. Time passed: 482 s. Flops: 6.7851E+02. Eff:70.677979%

The progress: 97.00%. Time passed: 487 s. Flops: 6.7830E+02. Eff:70.655815%

The progress: 98.00%. Time passed: 492 s. Flops: 6.7830E+02. Eff:70.656072%

The progress: 99.00%. Time passed: 498 s. Flops: 6.7694E+02. Eff:70.514278%

Finished. Time passed: 504 seconds.

```
=====
T/V N NB P Q Time Gflops

WR00L2L2 79897 192 4 6 503.60 6.752e+02
HPL_pdgesv() start time Fri Apr 22 15:19:54 2016

HPL_pdgesv() end time Fri Apr 22 15:28:18 2016
=====
```

$\|Ax-b\|_{\infty} / (\epsilon * (\|A\|_{\infty} * \|x\|_{\infty} + \|b\|_{\infty}) * N) = 0.0013370 \dots \text{PASSED}$

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.

End of Tests.

## 5.4 附录 3 整机测试输出文件

```
=====
HPLinpack 2.1 -- High-Performance Linpack benchmark -- October 26, 2012
Written by A. Petitet and R. Clint Whaley, Innovative Computing Laboratory, UTK
Modified by Piotr Luszczek, Innovative Computing Laboratory, UTK
Modified by Julien Langou, University of Colorado Denver
=====
```

An explanation of the input/output parameters follows:

```
T/V : Wall time / encoded variant.
N : The order of the coefficient matrix A.
NB : The partitioning blocking factor.
P : The number of process rows.
Q : The number of process columns.
Time : Time in seconds to solve the linear system.
Gflops : Rate of execution for solving the linear system.
```

The following parameter values will be used:

```
N : 622119
NB : 192
PMAP : Row-major process mapping
P : 36
Q : 40
PFACT : Left
NBMIN : 2
NDIV : 2
RFACT : Left
BCAST : lring
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:
```

- The relative machine precision (eps) is taken to be 2.220446e-16
- Computational tests pass if scaled residuals are less than 16.0

Begin

The progress: 1.00%. Time passed: 386 s. Flops: 4.2209E+03. Eff:73.280243%
The progress: 2.00%. Time passed: 723 s. Flops: 4.4917E+03. Eff:77.981043%
The progress: 3.00%. Time passed: 957 s. Flops: 5.0728E+03. Eff:88.070026%
The progress: 4.00%. Time passed: 1590 s. Flops: 4.0572E+03. Eff:70.437101%
The progress: 5.00%. Time passed: 1985 s. Flops: 4.0484E+03. Eff:70.285580%
The progress: 6.00%. Time passed: 2201 s. Flops: 4.4312E+03. Eff:76.930814%
The progress: 7.00%. Time passed: 2574 s. Flops: 4.3961E+03. Eff:76.321390%
The progress: 8.00%. Time passed: 3189 s. Flops: 4.0349E+03. Eff:70.050086%
The progress: 9.00%. Time passed: 3557 s. Flops: 4.0899E+03. Eff:71.004616%
The progress: 10.00%. Time passed: 3762 s. Flops: 4.2735E+03. Eff:74.192123%
The progress: 11.00%. Time passed: 4395 s. Flops: 4.0347E+03. Eff:70.047632%
The progress: 12.00%. Time passed: 4799 s. Flops: 4.0375E+03. Eff:70.095303%
The progress: 13.00%. Time passed: 4988 s. Flops: 4.2114E+03. Eff:73.114608%
The progress: 14.00%. Time passed: 5356 s. Flops: 4.1990E+03. Eff:72.900048%
The progress: 15.00%. Time passed: 5968 s. Flops: 4.0376E+03. Eff:70.097557%
The progress: 16.00%. Time passed: 6278 s. Flops: 4.0921E+03. Eff:71.044051%
The progress: 17.00%. Time passed: 6580 s. Flops: 4.1646E+03. Eff:72.302241%
The progress: 18.00%. Time passed: 7178 s. Flops: 4.0361E+03. Eff:70.071222%
The progress: 19.00%. Time passed: 7556 s. Flops: 4.0401E+03. Eff:70.140166%
The progress: 20.00%. Time passed: 7770 s. Flops: 4.1439E+03. Eff:71.942911%
The progress: 21.00%. Time passed: 8350 s. Flops: 4.0393E+03. Eff:70.126933%
The progress: 22.00%. Time passed: 8750 s. Flops: 4.0425E+03. Eff:70.182604%
The progress: 23.00%. Time passed: 8959 s. Flops: 4.1301E+03. Eff:71.703087%
The progress: 24.00%. Time passed: 9550 s. Flops: 4.0436E+03. Eff:70.202250%
The progress: 25.00%. Time passed: 9943 s. Flops: 4.0449E+03. Eff:70.223218%
The progress: 26.00%. Time passed: 10142 s. Flops: 4.1220E+03. Eff:71.562112%
The progress: 27.00%. Time passed: 10718 s. Flops: 4.0472E+03. Eff:70.264323%
The progress: 28.00%. Time passed: 11133 s. Flops: 4.0471E+03. Eff:70.262544%
The progress: 29.00%. Time passed: 11323 s. Flops: 4.1156E+03. Eff:71.451109%
The progress: 30.00%. Time passed: 11905 s. Flops: 4.0528E+03. Eff:70.360571%
The progress: 31.00%. Time passed: 12300 s. Flops: 4.0553E+03. Eff:70.403838%
The progress: 32.00%. Time passed: 12485 s. Flops: 4.1154E+03. Eff:71.447473%
The progress: 33.00%. Time passed: 13079 s. Flops: 4.0596E+03. Eff:70.478672%
The progress: 34.00%. Time passed: 13460 s. Flops: 4.0623E+03. Eff:70.526893%
The progress: 35.00%. Time passed: 13665 s. Flops: 4.1162E+03. Eff:71.461524%
The progress: 36.00%. Time passed: 14215 s. Flops: 4.0662E+03. Eff:70.593114%
The progress: 37.00%. Time passed: 14546 s. Flops: 4.0868E+03. Eff:70.951995%
The progress: 38.00%. Time passed: 14833 s. Flops: 4.1176E+03. Eff:71.485686%
The progress: 39.00%. Time passed: 15389 s. Flops: 4.0735E+03. Eff:70.720721%

The progress: 40.00%.	Time passed: 15609 s.	Flops: 4.1182E+03.	Eff:71.496658%
The progress: 41.00%.	Time passed: 16151 s.	Flops: 4.0776E+03.	Eff:70.791861%
The progress: 42.00%.	Time passed: 16547 s.	Flops: 4.0805E+03.	Eff:70.841887%
The progress: 43.00%.	Time passed: 16766 s.	Flops: 4.1191E+03.	Eff:71.511959%
The progress: 44.00%.	Time passed: 17319 s.	Flops: 4.0814E+03.	Eff:70.857103%
The progress: 45.00%.	Time passed: 17586 s.	Flops: 4.1107E+03.	Eff:71.366020%
The progress: 46.00%.	Time passed: 18092 s.	Flops: 4.0834E+03.	Eff:70.891970%
The progress: 47.00%.	Time passed: 18488 s.	Flops: 4.0859E+03.	Eff:70.936252%
The progress: 48.00%.	Time passed: 18721 s.	Flops: 4.1177E+03.	Eff:71.487722%
The progress: 49.00%.	Time passed: 19264 s.	Flops: 4.0859E+03.	Eff:70.935060%
The progress: 50.00%.	Time passed: 19508 s.	Flops: 4.1168E+03.	Eff:71.473072%
The progress: 51.00%.	Time passed: 20036 s.	Flops: 4.0872E+03.	Eff:70.959031%
The progress: 52.00%.	Time passed: 20282 s.	Flops: 4.1191E+03.	Eff:71.511301%
The progress: 53.00%.	Time passed: 20515 s.	Flops: 4.1516E+03.	Eff:72.076304%
The progress: 54.00%.	Time passed: 20887 s.	Flops: 4.1545E+03.	Eff:72.126084%
The progress: 55.00%.	Time passed: 21151 s.	Flops: 4.1774E+03.	Eff:72.523828%
The progress: 56.00%.	Time passed: 21668 s.	Flops: 4.1496E+03.	Eff:72.042190%
The progress: 57.00%.	Time passed: 21925 s.	Flops: 4.1749E+03.	Eff:72.481023%
The progress: 58.00%.	Time passed: 22437 s.	Flops: 4.1508E+03.	Eff:72.061720%
The progress: 59.00%.	Time passed: 22708 s.	Flops: 4.1740E+03.	Eff:72.465395%
The progress: 60.00%.	Time passed: 23225 s.	Flops: 4.1511E+03.	Eff:72.067448%
The progress: 61.00%.	Time passed: 23485 s.	Flops: 4.1732E+03.	Eff:72.451336%
The progress: 62.00%.	Time passed: 23985 s.	Flops: 4.1517E+03.	Eff:72.078698%
The progress: 63.00%.	Time passed: 24258 s.	Flops: 4.1719E+03.	Eff:72.428210%
The progress: 64.00%.	Time passed: 24765 s.	Flops: 4.1508E+03.	Eff:72.062001%
The progress: 65.00%.	Time passed: 25047 s.	Flops: 4.1694E+03.	Eff:72.385856%
The progress: 66.00%.	Time passed: 25534 s.	Flops: 4.1500E+03.	Eff:72.048353%
The progress: 67.00%.	Time passed: 25934 s.	Flops: 4.1495E+03.	Eff:72.040222%
The progress: 68.00%.	Time passed: 26260 s.	Flops: 4.1595E+03.	Eff:72.213162%
The progress: 69.00%.	Time passed: 26711 s.	Flops: 4.1484E+03.	Eff:72.021570%
The progress: 70.00%.	Time passed: 27000 s.	Flops: 4.1638E+03.	Eff:72.289058%
The progress: 71.00%.	Time passed: 27490 s.	Flops: 4.1471E+03.	Eff:71.998076%
The progress: 72.00%.	Time passed: 27783 s.	Flops: 4.1612E+03.	Eff:72.243704%
The progress: 73.00%.	Time passed: 28199 s.	Flops: 4.1577E+03.	Eff:72.183158%
The progress: 74.00%.	Time passed: 28675 s.	Flops: 4.1443E+03.	Eff:71.949203%
The progress: 75.00%.	Time passed: 28979 s.	Flops: 4.1564E+03.	Eff:72.160202%
The progress: 76.00%.	Time passed: 29373 s.	Flops: 4.1541E+03.	Eff:72.120198%
The progress: 77.00%.	Time passed: 29851 s.	Flops: 4.1425E+03.	Eff:71.919145%
The progress: 78.00%.	Time passed: 30239 s.	Flops: 4.1421E+03.	Eff:71.910777%
The progress: 79.00%.	Time passed: 30551 s.	Flops: 4.1521E+03.	Eff:72.084866%
The progress: 80.00%.	Time passed: 30961 s.	Flops: 4.1488E+03.	Eff:72.027715%
The progress: 81.00%.	Time passed: 31384 s.	Flops: 4.1438E+03.	Eff:71.940907%
The progress: 82.00%.	Time passed: 31692 s.	Flops: 4.1552E+03.	Eff:72.139471%

The progress: 83.00%. Time passed: 32076 s. Flops: 4.1547E+03. Eff:72.130440%

The progress: 84.00%. Time passed: 32465 s. Flops: 4.1545E+03. Eff:72.125969%

The progress: 85.00%. Time passed: 32794 s. Flops: 4.1624E+03. Eff:72.263809%

The progress: 86.00%. Time passed: 33179 s. Flops: 4.1622E+03. Eff:72.260864%

The progress: 87.00%. Time passed: 33566 s. Flops: 4.1619E+03. Eff:72.255680%

The progress: 88.00%. Time passed: 34004 s. Flops: 4.1552E+03. Eff:72.139317%

The progress: 89.00%. Time passed: 34390 s. Flops: 4.1555E+03. Eff:72.144300%

The progress: 90.00%. Time passed: 34770 s. Flops: 4.1557E+03. Eff:72.147207%

The progress: 91.00%. Time passed: 35109 s. Flops: 4.1613E+03. Eff:72.244951%

The progress: 92.00%. Time passed: 35534 s. Flops: 4.1567E+03. Eff:72.165472%

The progress: 93.00%. Time passed: 35887 s. Flops: 4.1607E+03. Eff:72.233757%

The progress: 94.00%. Time passed: 36296 s. Flops: 4.1580E+03. Eff:72.187477%

The progress: 95.00%. Time passed: 36675 s. Flops: 4.1588E+03. Eff:72.201712%

The progress: 96.00%. Time passed: 37056 s. Flops: 4.1595E+03. Eff:72.212970%

The progress: 97.00%. Time passed: 37412 s. Flops: 4.1629E+03. Eff:72.272460%

The progress: 98.00%. Time passed: 37805 s. Flops: 4.1618E+03. Eff:72.252856%

The progress: 99.00%. Time passed: 38179 s. Flops: 4.1631E+03. Eff:72.275566%

Finished. Time passed: 38580 seconds.

```
=====
T/V          N    NB    P    Q          Time          Gflops
-----
WR00L2L2      622119  192   36   40          38596.64          4.159e+03
HPL_pdgesv() start time Fri Apr 22 16:49:43 2016

HPL_pdgesv() end time   Sat Apr 23 03:33:00 2016
=====
```

```
||Ax-b||_oo/(eps*(||A||_oo*||x||_oo+||b||_oo)*N)=          0.0005241 ..... 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.

End of Tests.