

# Application benchmark results for Big Red, an IBM e1350 BladeCenter Cluster

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# 1. Introduction

The purpose of this report is to present the results of benchmark tests with Big Red, an IBM e1350 BladeCenter Cluster. This report is particularly focused on providing details of system architecture and test run results in detail to allow for analysis in other reports and comparison with other systems, rather than presenting such analysis here.

Big Red is based on the open blade cluster architecture [1], [2], employing the IBM JS21 blade and PowerPC 970MP processor. Having decided in early 2006 to make a major investment in an HPC system, Indiana University (IU) issued a call for proposals for a large supercomputer cluster on 3 March 2006. The system, purchased on 13 April 2006, was selected based on analysis of the proposals submitted by supercomputer vendors. After the initial 20.4 TFLOPS implementation, Big Red was upgraded to 30.72 TFLOPS in spring 2007. This upgrade was part of an economic development initiative in the state of Indiana (US), led jointly by Indiana University, Purdue University, the Indiana Economic Development Corporation (IEDC), and IBM, Inc. [3].

## 2. Hardware

### 2.a. Basic building blocks and system components

Big Red is based on the IBM JS21 Bladeserver node (used as user login nodes and compute nodes), configured as follows:

- 2 x 2.5GHz dual-core PowerPC 970MP processors
- 8GB 533MHz Double Data Rate, version 2 (DDR2) Synchronous Dynamic Random Access Memory (SDRAM)
- 73GB Serial Attached Small Computer System Interface (SAS) disk (67GB in /scratch)
- 1 x Myricom M3S-PCIXD-2-I (Lanai XP)

In addition to the JS21 Bladeserver node, there are storage nodes based on the IBM 505 pSeries 505 configured as follows:

- 2 x 1.65GHz dual-core Power5+ processor
- 8 GB 533MHz DDR2 SDRAM
- 73GB SAS disk
- 2 x Emulex LP10000 PCI-X/133MHz FC adapters

### 2.b. Initial 20.48 TFLOPS configuration

Big Red's initial 20.48 TFLOPS configuration was a distributed shared-memory cluster, consisting of 512 IBM JS21 blades, each with two dual-core PowerPC 970 MP processors, 8GB of memory, a 73B SAS disk, and a PCI-X Myrinet 2000 adapter for high-bandwidth, low-latency Message Passing Interface (MPI) applications. In addition to local scratch disks, the Big Red compute nodes are connected via gigabit Ethernet to a 266TB GPFS file system, hosted on 16 IBM p505 Power5 systems. Two 256-port Myricom M3-CLOS-ENCL switches provide a 2+2Gb/s low-latency interconnect for the 512 compute nodes. The allocation of nodes is described in Table 1 below.

Use	Node type	#
User login	JS21	4
Compute	JS21	512
Storage	pSeries 505	16

Table 1.

The disk for Big Red's 266TB GPFS volume is hosted on 10 DataDirect Networks S2A 9500 storage controllers, each dual-pathed to 5 Service Availability Forum (standard) (SAF) 4248 chassis. Physical disks are aggregated in an 8+2 Redundant Array of Independent (or Inexpensive) Disks (RAID) configuration; combined with the dual-pathed controllers and active/active GPFS storage hosts, this provides multiple levels of redundancy for Big Red's storage space.

Home directories are available via NFSv3 over Gigabit Ethernet. They are housed in an IBM N5500 A20. They consist of two nodes. Each node contains:

- 2 Intel 2.8 GHz Xeon processors,
- 4 GB of Error Correction Codes (ECC) memory
- 512 MB of non-volatile random access memory (NVRAM)
- 4 integrated 10/100/1000 Ethernet ports
- 4 integrated 2 Gbps Fibre Channel ports
- 2 redundant hot-plug integrated power supplies and cooling fans
- 3 PCI-X expansion slots for additional FC HBAs or Ethernet NICs
- Infiniband (IB) cluster interconnect between the two processing nodes

### **2.c. Expanded 30.72 TFLOPS configuration**

Big Red's 30.72 TFLOPS configuration is a distributed memory cluster, consisting of 768 IBM JS21 blades, each with two dual-core PowerPC 970 MP processors, 8GB of memory, a 73B SAS disk, and a PCI-X Myrinet 2000 adapter for high-bandwidth, low-latency MPI applications. In addition to local scratch disks, the Big Red compute nodes are connected via gigabit Ethernet to a 266TB GPFS file system, hosted on 16 IBM p505 Power5 systems. Four 256-port Myricom M3-CLOS-ENCL switches provide a 2+2Gb/s low-latency interconnect for the 768 compute nodes. The allocation of nodes is described in Table 2 below.

Use	Node type	#
User Login	JS21	4
Compute	JS21	768
Storage	pSeries 505	16

**Table 2.**

## **3. System software**

The Big Red cluster runs the SuSE Linux Enterprise Server (SLES) operating system. Batch jobs are managed with IBM's LoadLeveler and the Moab Workload Manager. Big Red uses LoadLeveler to submit and monitor jobs. LoadLeveler relies on the Moab scheduler software for job scheduling, incorporating a fair share mechanism based on research system time used by each user trying to run a job.

Compilers on Big Red:

- GCC version 3.3.3
- IBM compilers:
  - C compiler: xlc version 8.0
  - C++ compiler xlc version 8.0
  - Fortran compiler: xlf/xlf90 version 10.1

Message passing libraries:

```
MPICH Version: 1.2.7
MPICH Release date: 2005/11/08 03:56:31
MPICH Patches applied: none
MPICH configure: --with-device=ch_mx -prefix=/N/soft/linux-sles9-ppc64/mpich-mx-ibm-64 -opt= -O -
lib= -WI,-rpath,/opt/mx/lib64,-rpath,/opt/mx/lib -L/opt/mx/lib64 -L/opt/mx/lib/ -lmyriexpress
MPICH Device: ch_mx
```

## **4. System architecture benchmarks**

We ran the HPC Challenge Benchmarks [4] as specified in the National Science Foundation (NSF) Benchmark guidance document NSF 06-05 [5].

#### 4.a. System architecture benchmarks utilizing 1024 cores

System Architecture benchmarks run on Big Red with its initial 20.48 TFLOPS configuration were run using SUSE Linux SLES 9, update 3.

The system benchmarks performed are summarized here. Detailed benchmark results are available in section 6. Benchmarks were run without modifications to the run and make files provided as part of the NSF benchmark suite.

- High Performance Linpack (HPL) – the Linpack TPP benchmark, which measures the floating point rate of execution for solving a linear system of equations.
  - Time to completion: 199.22 seconds
  - Speed: 3.346e+03 GFLOPS
- Double precision, General Equation, Matrix Multiply (DGEMM)M – measures the floating point rate of execution of double precision real matrix-matrix multiplication.
  - StarDGEMM
    - Minimum GFLOPS: 4.538
    - Average GFLOPS: 7.009
    - Maximum GFLOPS: 7.552
  - SingleDGEMM
    - Single DGEMM GFLOPS: 7.874
- STREAM – a simple synthetic benchmark program that measures sustainable memory bandwidth (in GB/s) and the corresponding computation rate for simple vector kernel.

- StarSTREAM

Function	Rate (GB/s)
Copy	2.986
Scale	3.023
Add	3.145
Triad	3.244

**Table 3.**

- SingleSTREAM

Function	Rate (GB/s)	Avg time	Min time	Max time
Copy	1.0220	0.0176	0.0175	0.0177
Scale	1.0678	0.0169	0.0168	0.0170
Add	1.1617	1.2032	1.0231	1.0233
Triad	1.2247	0.0235	0.0220	0.0240

**Table 4.**

- PTRANS (parallel matrix transpose) – exercises the communications where pairs of processors communicate with each other simultaneously. It is a useful test of the total communications capacity of the network.
  - Average CPU time to completion: 23.997 seconds
  - Average wall clock time to completion: 26.687 seconds
  - Average speed: 25.112 GB/s
- RandomAccess – measures the rate of integer random updates of memory (GUPS).
  - MPIRandomAccess
    - CPU time used: 62.250 seconds
    - Wall clock time used: 62.290 seconds
    - Updates per second [GUP/s]: 0.1799E+09
    - Updates/PE per second [GUP/s]: 0.00018E+09
  - StarRandomAccess
    - CPU time used: 11.830 seconds

- Wall clock time used: 11.836 seconds
- Average GUP/s: 0.0028 billion ( $10^9$ )
- SingleRandomAccess
  - Single GUP/s 0.004045
- FFTE – measures the floating-point rate of execution of double precision complex one-dimensional Discrete Fourier Transform (DFT).
  - MPIFFT
    - Generation time: 0.178 seconds
    - Tuning: 0.164 seconds
    - Computing: 3.567 seconds
    - Inverse FFT: 3.469 seconds
  - StarFFT
    - Generation time: 0.357 seconds
    - Tuning: 0.001 seconds
    - Computing: 0.481 seconds
    - Inverse FFT: 3.649 seconds
    - Average GFLOPS: 0.451
  - SingleFFT
    - GFLOP/S: 0.718
- Communication bandwidth and latency – a set of tests to measure latency and bandwidth of a number of simultaneous communications patterns; based on b\_eff (effective bandwidth benchmark).
  - Max Ping Pong Latency: 0.005811 msec
  - Randomly Ordered Ring Latency: 0.017495 msec
  - Min Ping Pong Bandwidth: 195.131555 MB/s
  - Naturally Ordered Ring Bandwidth: 135.169320 MB/s
  - Randomly Ordered Ring Bandwidth: 23.885499 MB/s

#### **4.b. System architecture benchmarks utilizing 2048 cores**

System Architecture Benchmarks run on Big Red with its 30.72 TFLOPS configuration were run using the SUSE Linux SLES 9, update 3.

A subset of the previously described benchmarks was performed on the upgraded system and is summarized here. Detailed benchmark results are available in section 6. Benchmarks were run without modifications to the run and make files provided as part of the NSF benchmark suite.

- HPL – the Linpack TPP benchmark which measures the floating point rate of execution for solving a linear system of equations.
  - Time to completion: 10641.34 seconds
  - Speed:  $1.353e+04$  GFLOPS
- DGEMM – measures the floating point rate of execution of double precision real matrix-matrix multiplication.
  - StarDGEMM
    - Minimum GFLOPS: 6.793
    - Average GFLOPS: 8.269
    - Maximum GFLOPS: 8.320
  - SingleDGEMM
    - Single DGEMM GFLOPS: 8.494

Function	Rate (GB/s)
Copy	2.959

Scale	3.0509
Add	3.318
Triad	3.312

**Table 5.**

- STREAM – a simple synthetic benchmark program that measures sustainable memory bandwidth (in GB/s) and the corresponding computation rate for simple vector kernel.
  - StarSTREAM
    - Not performed.
  - SingleSTREAM
    - Not performed.
- PTRANS (parallel matrix transpose) – exercises the communications where pairs of processors communicate with each other simultaneously. It is a useful test of the total communications capacity of the network.
  - Average wall clock time to completion: 26.95 seconds
  - Average CPU time to completion: 26.71 seconds
  - Average speed: 28.955 GB/s
- RandomAccess – measures the rate of integer random updates of memory (GUPS).
  - MPIRandomAccess
    - CPU time used: 61.37 seconds
    - Wall clock time used: 61.41 seconds
    - Updates per second [GUP/s]: 0.2497 billion ( $10^9$ )
    - Updates/PE per second [GUP/s]: 0.00012 billion ( $10^9$ )
  - StarRandomAccess
    - CPU time used: 211.78 seconds
    - Wall clock time used: 211.81 seconds
    - Average GUP/s: 0.0025 billion ( $10^9$ )
  - SingleRandomAccess
    - GUP/s: 0.0035 billion ( $10^9$ )
- FFTE – measures the floating-point rate of execution of double precision complex one-dimensional Discrete Fourier Transform (DFT).

Function	Rate (GB/s)	Avg time	Min time	Max time
Copy	1.0377	0.0176	0.0175	0.0177
Scale	1.0497	0.0169	0.0168	0.0170
Add	1.1782	1.2032	1.0231	1.0233
Triad	1.941	0.0235	0.0220	0.0240

**Table 6.**

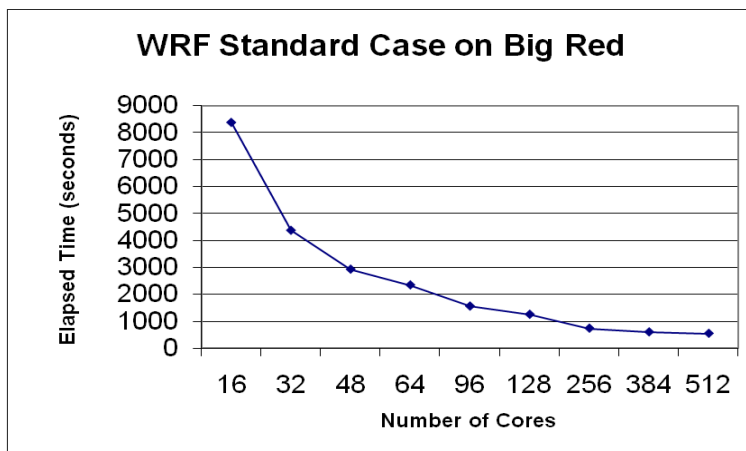
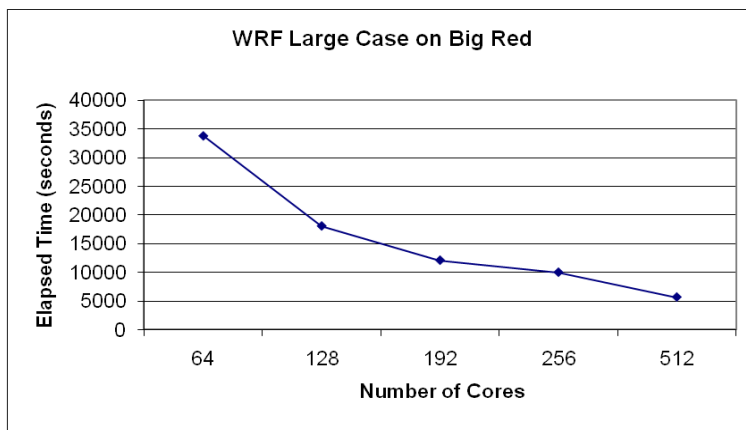
- MPIFFT
  - Generation time: 2.846 seconds
  - Tuning: 2.592 seconds
  - Computing: 43.377 seconds
  - Inverse FFT: 44.124 seconds
- StarFFT
  - Generation time: 5.694 seconds
  - Tuning: 0.003 seconds
  - Computing: 10.507 seconds
  - Inverse FFT: 11.355 seconds
  - Average GFLOPS: 0.399

- SingleFFT
  - GFLOPS: 0.436
- Communication bandwidth and latency – a set of tests to measure latency and bandwidth of a number of simultaneous communications patterns; based on b\_eff (effective bandwidth benchmark).
  - Max Ping Pong Latency: 0.006124 msec
  - Randomly Ordered Ring Latency: 0.017735 msec
  - Min Ping Pong Bandwidth: 195.954309 MB/s
  - Naturally Ordered Ring Bandwidth: 92.852883 MB/s
  - Randomly Ordered Ring Bandwidth: 21.201995 MB/s

## 5. Application benchmarks

Use of Big Red is aimed at a large user community with diverse computational needs. Performance of several applications was measured to provide information about expected performance under real-use conditions.

- WRF – A next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs [6]. Expanded charted data are in section 6.c.1.



- OOCORE1 – Out-of-core solver software code developed by the SCALAPACK group at the University of Tennessee at Knoxville [7].
- GAMESS1 – General Atomic and Molecular Electronic Structure System. a general ab initio quantum chemistry package [8]. Expanded data are in section 6.c.3.

# Processors	# Nodes	# Cores	Time				Linear Scaling				Scaling Efficiency			
			NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large
1	1	1												
1	1	2												
2	1	4												
4	2	8												
8	4	16		14508				1				1		
16	8	32		7917				7254				0.91625616		
32	16	64		4626				3627				0.78404669		
64	32	128		3090	23459			1813.5	1			0.5868932	1	
96	48	192		2843	15757			1209	15639.3333			0.42525501	0.99253242	
128	64	256		2837	12103			906.75	11729.5			0.31961579	0.96913988	
160	80	320			9976				9383.6				0.94061748	
192	96	384			8593				7819.66667				0.91000427	
224	112	448			7545				6702.57143				0.91000427	
256	128	512			6869				5864.75				0.85379968	
384	192	768			5283				3909.83333				0.74007824	
448	224	896			4923				3351.28571				0.68074055	
512	256	1024			4641				2932.375				0.6318412	
1024	512	2048												
1536	768	3072												
2048	1024	4096												

**Table 7. GAMESS benchmarks.**



- MILC2 – Large-scale numerical simulations software to study quantum chromodynamics (QCD), the theory of the strong interactions of subatomic physics [9]. Expanded charted data are in section 6.c.4.

		Core Count								
		1	16	32	64	128	256	512	1024	2048
Test Case	small	92.581								
	medium		1683.432	865.036	447.845	235.026	122.015			
	large				11316.27	5781.716	2964.596	1537.605	817	452
	x-large								6554	3695
	small Target	91								
	medium Target		1680	855	443	242	143			
	large Target				11821	6282	3499	2102	1371	

Table 8.

- PARATEC2 – Parallel Total Energy Code. A package designed primarily for a massively parallel computing platform. The code performs ab-initio quantum-mechanical total energy calculations using pseudopotentials and a plane wave basis set [10]. Expanded charted data are in section 6.c.5.

		Core Count					
		4	32	64	128	256	512
Test Case	small	4					
	medium		1323	737	518		
	large			3794	2415	2068	
	IU case1						
	IU case2						
	IU case3						

Table 9. Tuning level.

- HOMME3 – High Order Methods Modeling Environment, tools to create a high-performance scalable global atmospheric model [11].

## 6. Architecture benchmark output files

### 6.a. HPCCL benchmark data for initial 1024 core configuration

```

Hostname: 's1c1b1'
#####
=====
HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004
Written by A. Petit et and R. Clint Whaley, Innovative Computing Labs., UTK
=====

```

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      : 100000
NB     : 200
PMAP   : Row-major process mapping
P      : 31
Q      : 96

```

```

PFACT : Left
NBMIN : 4
NDIV : 2
RFACT : Right
BCAST : 2ringM
DEPTH : 0
SWAP : Mix (threshold = 64)
L1 : transposed form
U : transposed form
EQUIL : yes
ALIGN : 16 double precision words

```

```

-----
- The matrix A is randomly generated for each test.
- The following scaled residual checks will be computed:
  1)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N)$ 
  2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$ 
  3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$ 
- The relative machine precision (eps) is taken to be 1.110223e-16
- Computational tests pass if scaled residuals are less than 16.0

```

Begin of PTRANS section.

```

M: 50000
N: 50000
MB: 200 100 200
NB: 200 100 200
P: 31
Q: 96

```

	M	N	MB	NB	P	Q	TIME	CHECK	GB/s	RESID
WALL	50000	50000	200	200	31	96	49.60	PASSED	0.403	0.00
CPU	50000	50000	200	200	31	96	49.62	PASSED	0.403	0.00
WALL	50000	50000	100	100	31	96	12.97	PASSED	1.542	0.00
CPU	50000	50000	100	100	31	96	13.00	PASSED	1.538	0.00
WALL	50000	50000	200	200	31	96	49.52	PASSED	0.404	0.00
CPU	50000	50000	200	200	31	96	49.55	PASSED	0.404	0.00

```

Finished 3 tests, with the following results:
  3 tests completed and passed residual checks.
  0 tests completed and failed residual checks.
  0 tests skipped because of illegal input values.

```

```

END OF TESTS.
Current time (1182228795) is Tue Jun 19 00:53:15 2007

```

```

End of PTRANS section.
Begin of HPL section.

```

```

=====
HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004
Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK
=====

```

```

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 : 100000
NB : 200
PMAP : Row-major process mapping

```

```

P      :      31
Q      :      96
PFACT :      Left
NBMIN  :      4
NDIV   :      2
RFACT  :      Right
BCAST  :      2ringM
DEPTH  :      0
SWAP   :      Mix (threshold = 64)
L1     :      transposed form
U      :      transposed form
EQUIL  :      yes
ALIGN  :      16 double precision words

```

```

-----
- The matrix A is randomly generated for each test.
- The following scaled residual checks will be computed:
  1) ||Ax-b||_oo / ( eps * ||A||_1 * N )
  2) ||Ax-b||_oo / ( eps * ||A||_1 * ||x||_1 )
  3) ||Ax-b||_oo / ( eps * ||A||_oo * ||x||_oo )
- 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
-----
WR03R2L4    100000  200    31    96          111.25          5.993e+03

```

```

=====
||Ax-b||_oo / ( eps * ||A||_1 * N ) =      0.0197702 ..... PASSED
||Ax-b||_oo / ( eps * ||A||_1 * ||x||_1 ) =      0.0132985 ..... PASSED
||Ax-b||_oo / ( eps * ||A||_oo * ||x||_oo ) =      0.0023911 ..... 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.

```

```

=====
Current time (1182228906) is Tue Jun 19 00:55:06 2007

```

```

End of HPL section.
Begin of StarDGEMM section.
Scaled residual: 0.00618034
Node(s) with error 0
Minimum Gflop/s 4.538357
Average Gflop/s 7.008804
Maximum Gflop/s 7.551706
Current time (1182228907) is Tue Jun 19 00:55:07 2007

```

```

End of StarDGEMM section.
Begin of SingleDGEMM section.
Node(s) with error 0
Node selected 2000
Single DGEMM Gflop/s 7.873863
Current time (1182228908) is Tue Jun 19 00:55:08 2007

```

```

End of SingleDGEMM section.
Begin of StarSTREAM section.

```

```

-----
This system uses 8 bytes per DOUBLE PRECISION word.

```

```

-----
Array size = 1120071, Offset = 0
Total memory required = 0.0250 GB.

```

Each test is run 10 times, but only the \*best\* time for each is used.

-----  
Your clock granularity/precision appears to be 1 microseconds.  
Each test below will take on the order of 11660 microseconds.  
(= 11660 clock ticks)  
Increase the size of the arrays if this shows that  
you are not getting at least 20 clock ticks per test.  
-----

WARNING -- The above is only a rough guideline.  
For best results, please be sure you know the  
precision of your system timer.

-----  
Function           Rate (GB/s)   Avg time       Min time       Max time  
Copy:             1.0220       0.0176        0.0175        0.0177  
Scale:            1.0678       0.0169        0.0168        0.0170  
Add:              1.1617       0.0232        0.0231        0.0233  
Triad:            1.2247       0.0235        0.0220        0.0240  
-----

Results Comparison:  
  Expected   : 1291778759355468800.000000 258355751871093760.000000  
344474335828124992.000000  
  Observed   : 1291778759353353728.000000 258355751869478400.000000  
344474335828124992.000000  
Solution Validates

-----  
Node(s) with error 0  
Minimum Copy GB/s 0.972553  
Average Copy GB/s 1.036761  
Maximum Copy GB/s 1.496659  
Minimum Scale GB/s 0.990273  
Average Scale GB/s 1.040788  
Maximum Scale GB/s 1.562295  
Minimum Add GB/s 1.042977  
Average Add GB/s 1.140035  
Maximum Add GB/s 1.529104  
Minimum Triad GB/s 1.075315  
Average Triad GB/s 1.173333  
Maximum Triad GB/s 2.186392  
Current time (1182228909) is Tue Jun 19 00:55:09 2007

End of StarSTREAM section.  
Begin of SingleSTREAM section.  
Node(s) with error 0  
Node selected 1143  
Single STREAM Copy GB/s 2.985886  
Single STREAM Scale GB/s 3.023113  
Single STREAM Add GB/s 3.144787  
Single STREAM Triad GB/s 3.243859  
Current time (1182228909) is Tue Jun 19 00:55:09 2007

End of SingleSTREAM section.  
Begin of MPIRandomAccess section.  
#####  
This is the DARPA/DOE HPC Challenge Benchmark version 1.0.0 October 2003  
Produced by Jack Dongarra and Piotr Luszczek  
Innovative Computing Laboratory  
University of Tennessee Knoxville and Oak Ridge National Laboratory

See the source files for authors of specific codes.  
Compiled on Jun 18 2007 at 11:44:38  
Current time (1182262355) is Tue Jun 19 10:12:35 2007

Hostname: 's1clb1'  
#####  
=====

HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004

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 : 100000  
NB : 200  
PMAP : Row-major process mapping  
P : 32  
Q : 32  
PFACT : Left  
NBMIN : 4  
NDIV : 2  
RFACT : Right  
BCAST : 2ringM  
DEPTH : 0  
SWAP : Mix (threshold = 64)  
L1 : transposed form  
U : transposed form  
EQUIL : yes  
ALIGN : 16 double precision words

- 
- The matrix A is randomly generated for each test.
  - The following scaled residual checks will be computed:
    - 1)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N)$
    - 2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$
    - 3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$
  - The relative machine precision (eps) is taken to be 1.110223e-16
  - Computational tests pass if scaled residuals are less than 16.0

Begin of PTRANS section.

M: 50000  
N: 50000  
MB: 200 100 200  
NB: 200 100 200  
P: 32  
Q: 32

TIME	M	N	MB	NB	P	Q	TIME	CHECK	GB/s	RESID
WALL	50000	50000	200	200	32	32	1.26	PASSED	15.859	0.00
CPU	50000	50000	200	200	32	32	1.27	PASSED	15.748	0.00
WALL	50000	50000	100	100	32	32	1.26	PASSED	15.931	0.00
CPU	50000	50000	100	100	32	32	1.27	PASSED	15.748	0.00
WALL	50000	50000	200	200	32	32	1.26	PASSED	15.873	0.00
CPU	50000	50000	200	200	32	32	1.26	PASSED	15.873	0.00

Finished 3 tests, with the following results:  
3 tests completed and passed residual checks.  
0 tests completed and failed residual checks.  
0 tests skipped because of illegal input values.

END OF TESTS.

Current time (1182262368) is Tue Jun 19 10:12:48 2007

End of PTRANS section.

Begin of HPL section.

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 : 100000  
 NB : 200  
 PMAP : Row-major process mapping  
 P : 32  
 Q : 32  
 PFACT : Left  
 NBMIN : 4  
 NDIV : 2  
 RFACT : Right  
 BCAST : 2ringM  
 DEPTH : 0  
 SWAP : Mix (threshold = 64)  
 L1 : transposed form  
 U : transposed form  
 EQUIL : yes  
 ALIGN : 16 double precision words

-----  
 - The matrix A is randomly generated for each test.  
 - The following scaled residual checks will be computed:  
 1)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N)$   
 2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 - 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
WR03R2L4	100000	200	32	32	199.22	3.346e+03
-----						
$\frac{\ Ax-b\ _{\infty}}{\ A\ _{\infty}} / (\text{eps} * \ A\ _{\infty} * N)$					0.0146222	..... PASSED
$\frac{\ Ax-b\ _{\infty}}{\ A\ _{\infty}} / (\text{eps} * \ A\ _{\infty} * \ x\ _{\infty})$					0.0098357	..... PASSED
$\frac{\ Ax-b\ _{\infty}}{\ A\ _{\infty}} / (\text{eps} * \ A\ _{\infty} * \ x\ _{\infty})$					0.0017685	..... 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.

=====
  
Current time (1182262568) is Tue Jun 19 10:16:08 2007

End of HPL section.  
 Begin of StarDGEMM section.  
 Scaled residual: 0.00510712  
 Node(s) with error 0

Minimum Gflop/s 7.262569  
Average Gflop/s 7.564677  
Maximum Gflop/s 7.745041  
Current time (1182262570) is Tue Jun 19 10:16:10 2007

End of StarDGEMM section.  
Begin of SingleDGEMM section.  
Node(s) with error 0  
Node selected 823  
Single DGEMM Gflop/s 8.091957  
Current time (1182262572) is Tue Jun 19 10:16:12 2007

End of SingleDGEMM section.  
Begin of StarSTREAM section.

-----  
This system uses 8 bytes per DOUBLE PRECISION word.  
-----

Array size = 3255208, Offset = 0  
Total memory required = 0.0728 GB.  
Each test is run 10 times, but only  
the \*best\* time for each is used.  
-----

Your clock granularity/precision appears to be 1 microseconds.  
Each test below will take on the order of 33359 microseconds.  
(= 33359 clock ticks)  
Increase the size of the arrays if this shows that  
you are not getting at least 20 clock ticks per test.  
-----

WARNING -- The above is only a rough guideline.  
For best results, please be sure you know the  
precision of your system timer.  
-----

Function	Rate (GB/s)	Avg time	Min time	Max time
Copy:	1.3551	0.0463	0.0384	0.0497
Scale:	1.3465	0.0476	0.0387	0.0504
Add:	1.5210	0.0644	0.0514	0.0683
Triad:	1.4984	0.0640	0.0521	0.0682

-----

Results Comparison:  
Expected : 3754233929531250176.000000 750846785906249984.000000  
1001129047875000064.000000  
Observed : 3754233929605240320.000000 750846785916409344.000000  
1001129047886046464.000000  
Solution Validates  
-----

Node(s) with error 0  
Minimum Copy GB/s 1.032456  
Average Copy GB/s 1.783751  
Maximum Copy GB/s 3.059742  
Minimum Scale GB/s 1.033463  
Average Scale GB/s 1.745111  
Maximum Scale GB/s 2.983031  
Minimum Add GB/s 1.173118  
Average Add GB/s 1.975090  
Maximum Add GB/s 3.382328  
Minimum Triad GB/s 1.176597  
Average Triad GB/s 1.976104  
Maximum Triad GB/s 3.383656  
Current time (1182262575) is Tue Jun 19 10:16:15 2007

End of StarSTREAM section.  
Begin of SingleSTREAM section.  
Node(s) with error 0  
Node selected 96  
Single STREAM Copy GB/s 3.016144  
Single STREAM Scale GB/s 2.940390  
Single STREAM Add GB/s 3.319387

Single STREAM Triad GB/s 3.318245  
Current time (1182262576) is Tue Jun 19 10:16:16 2007

End of SingleSTREAM section.  
Begin of MPIRandomAccess section.  
Running on 1024 processors (PowerofTwo)  
Total Main table size =  $2^{33}$  = 8589934592 words  
PE Main table size =  $2^{23}$  = 8388608 words/PE  
Default number of updates (RECOMMENDED) = 34359738368  
Number of updates EXECUTED = 11208680448 (for a TIME BOUND of 60.00 secs)  
CPU time used = 62.250000 seconds  
Real time used = 62.290993 seconds  
0.179940629 Billion( $10^9$ ) Updates per second [GUP/s]  
0.000175723 Billion( $10^9$ ) Updates/PE per second [GUP/s]  
Verification: CPU time used = 25.810000 seconds  
Verification: Real time used = 27.247278 seconds  
Found 0 errors in 8589934592 locations (passed).  
Current time (1182262667) is Tue Jun 19 10:17:47 2007

End of MPIRandomAccess section.  
Begin of StarRandomAccess section.  
Main table size =  $2^{23}$  = 8388608 words  
Number of updates = 33554432  
CPU time used = 11.830000 seconds  
Real time used = 11.835544 seconds  
0.002835056 Billion( $10^9$ ) Updates per second [GUP/s]  
Found 0 errors in 8388608 locations (passed).  
Node(s) with error 0  
Minimum GUP/s 0.002813  
Average GUP/s 0.002834  
Maximum GUP/s 0.002875  
Current time (1182262691) is Tue Jun 19 10:18:11 2007

End of StarRandomAccess section.  
Begin of SingleRandomAccess section.  
Node(s) with error 0  
Node selected 686  
Single GUP/s 0.004045  
Current time (1182262708) is Tue Jun 19 10:18:28 2007

End of SingleRandomAccess section.  
Begin of MPIFFT section.  
Number of nodes: 1024  
Vector size: 1073741824  
Generation time: 0.178  
Tuning: 0.164  
Computing: 3.567  
Inverse FFT: 3.649  
 $\max(|x-x_0|)$ : 1.788e-15  
Current time (1182262716) is Tue Jun 19 10:18:36 2007

End of MPIFFT section.  
Begin of StarFFT section.  
Vector size: 2097152  
Generation time: 0.357  
Tuning: 0.001  
Computing: 0.481  
Inverse FFT: 0.526  
 $\max(|x-x_0|)$ : 1.617e-15  
Node(s) with error 0  
Minimum Gflop/s 0.415081  
Average Gflop/s 0.450625  
Maximum Gflop/s 0.480677  
Current time (1182262718) is Tue Jun 19 10:18:38 2007

End of StarFFT section.  
Begin of SingleFFT section.



Node(s) with error 0  
Node selected 350  
Single FFT Gflop/s 0.717585  
Current time (1182262719) is Tue Jun 19 10:18:39 2007

End of SingleFFT section.  
Begin of LatencyBandwidth section.

-----  
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart  
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany

Details - level 2  
-----

MPI\_Wtime granularity.  
Max. MPI\_Wtick is 0.000001 sec  
wtick is set to 0.000001 sec

Message Length: 8  
Latency min / avg / max: 0.005677 / 0.005677 / 0.005677 msecs  
Bandwidth min / avg / max: 1.409 / 1.409 / 1.409 MByte/s

MPI\_Wtime granularity is ok.

message size: 8  
max time : 10.000000 secs  
latency for msg: 0.005677 msecs  
estimation for ping pong: 0.510961 msecs  
max number of ping pong pairs = 19570  
max client pings = max server pongs = 139  
stride for latency = 11  
Message Length: 8  
Latency min / avg / max: 0.004366 / 0.004993 / 0.005811 msecs  
Bandwidth min / avg / max: 1.377 / 1.605 / 1.832 MByte/s

Message Length: 2000000  
Latency min / avg / max: 10.192990 / 10.192990 / 10.192990 msecs  
Bandwidth min / avg / max: 196.213 / 196.213 / 196.213 MByte/s

MPI\_Wtime granularity is ok.

message size: 2000000  
max time : 30.000000 secs  
latency for msg: 10.192990 msecs  
estimation for ping pong: 81.543922 msecs  
max number of ping pong pairs = 367  
max client pings = max server pongs = 19  
stride for latency = 59  
Message Length: 2000000  
Latency min / avg / max: 10.137081 / 10.178978 / 10.249496 msecs  
Bandwidth min / avg / max: 195.132 / 196.484 / 197.295 MByte/s

Message Size: 8 Byte  
Natural Order Latency: 0.006104 msec  
Natural Order Bandwidth: 1.310720 MB/s  
Avg Random Order Latency: 0.017494 msec  
Avg Random Order Bandwidth: 0.457310 MB/s

Message Size: 2000000 Byte  
Natural Order Latency: 14.796257 msec  
Natural Order Bandwidth: 135.169320 MB/s  
Avg Random Order Latency: 83.732812 msec  
Avg Random Order Bandwidth: 23.885499 MB/s

Execution time (wall clock) = 63.332 sec on 1024 processes  
- for cross ping\_pong latency = 4.310 sec  
- for cross ping\_pong bandwidth = 26.381 sec  
- for ring latency = 0.443 sec

- for ring bandwidth = 32.198 sec

-----  
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart  
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany

Major Benchmark results:

-----  
Max Ping Pong Latency: 0.005811 msec  
Randomly Ordered Ring Latency: 0.017494 msec  
Min Ping Pong Bandwidth: 195.131555 MB/s  
Naturally Ordered Ring Bandwidth: 135.169320 MB/s  
Randomly Ordered Ring Bandwidth: 23.885499 MB/s

-----  
Detailed benchmark results:

Ping Pong:

Latency min / avg / max: 0.004366 / 0.004993 / 0.005811 msec  
Bandwidth min / avg / max: 195.132 / 196.484 / 197.295 MByte/s

Ring:

On naturally ordered ring: latency= 0.006104 msec, bandwidth= 135.169320 MB/s  
On randomly ordered ring: latency= 0.017494 msec, bandwidth= 23.885499 MB/s

-----  
Benchmark conditions:

The latency measurements were done with 8 bytes  
The bandwidth measurements were done with 2000000 bytes  
The ring communication was done in both directions on 1024 processes  
The Ping Pong measurements were done on  
- 8742 pairs of processes for latency benchmarking, and  
- 324 pairs of processes for bandwidth benchmarking,  
out of  $1024 \cdot (1024 - 1) = 1047552$  possible combinations on 1024 processes.  
(1 MB/s =  $10^6$  byte/sec)

-----  
Current time (1182262782) is Tue Jun 19 10:19:42 2007

End of LatencyBandwidth section.

Begin of Summary section.

VersionMajor=1  
VersionMinor=0  
VersionMicro=0  
VersionRelease=b  
LANG=C  
Success=1  
sizeof\_char=1  
sizeof\_short=2  
sizeof\_int=4  
sizeof\_long=8  
sizeof\_void\_ptr=8  
sizeof\_size\_t=8  
sizeof\_float=4  
sizeof\_double=8  
sizeof\_s64Int=8  
sizeof\_u64Int=8  
CommWorldProcs=1024  
MPI\_Wtick=9.536743e-07  
HPL\_Tflops=3.34646  
HPL\_time=199.22  
HPL\_eps=1.11022e-16  
HPL\_RnormI=4.0893e-09  
HPL\_Anorm1=25189.8  
HPL\_AnormI=25157.5  
HPL\_Xnorm1=148665  
HPL\_XnormI=8.2789

HPL\_N=100000  
HPL\_NB=200  
HPL\_nprow=32  
HPL\_npcol=32  
HPL\_depth=0  
HPL\_nbdiv=2  
HPL\_nbmin=4  
HPL\_cpfact=L  
HPL\_crfact=R  
HPL\_ctop=3  
HPL\_order=R  
HPL\_dMACH\_EPS=1.110223e-16  
HPL\_dMACH\_SFMIN=2.225074e-308  
HPL\_dMACH\_BASE=2.000000e+00  
HPL\_dMACH\_PREC=2.220446e-16  
HPL\_dMACH\_MLEN=5.300000e+01  
HPL\_dMACH\_RND=1.000000e+00  
HPL\_dMACH\_EMIN=-1.021000e+03  
HPL\_dMACH\_RMIN=2.225074e-308  
HPL\_dMACH\_EMAX=1.024000e+03  
HPL\_dMACH\_RMAX=1.797693e+308  
HPL\_sMACH\_EPS=5.960464e-08  
HPL\_sMACH\_SFMIN=1.175494e-38  
HPL\_sMACH\_BASE=2.000000e+00  
HPL\_sMACH\_PREC=1.192093e-07  
HPL\_sMACH\_MLEN=2.400000e+01  
HPL\_sMACH\_RND=1.000000e+00  
HPL\_sMACH\_EMIN=-1.250000e+02  
HPL\_sMACH\_RMIN=1.175494e-38  
HPL\_sMACH\_EMAX=1.280000e+02  
HPL\_sMACH\_RMAX=3.402823e+38  
dweeps=1.110223e-16  
sweps=5.960464e-08  
HPLMaxProcs=1024  
HPLMinProcs=1024  
DGEMM\_N=1562  
StarDGEMM\_Gflops=7.56468  
SingleDGEMM\_Gflops=8.09196  
PTRANS\_GBs=15.931  
PTRANS\_time=1.25541  
PTRANS\_residual=0  
PTRANS\_n=50000  
PTRANS\_nb=100  
PTRANS\_nprow=32  
PTRANS\_npcol=32  
MPIRandomAccess\_N=8589934592  
MPIRandomAccess\_time=62.291  
MPIRandomAccess\_CheckTime=27.2473  
MPIRandomAccess\_Errors=0  
MPIRandomAccess\_ErrorsFraction=0  
MPIRandomAccess\_ExeUpdates=11208680448  
MPIRandomAccess\_GUPs=0.179941  
MPIRandomAccess\_TimeBound=60  
RandomAccess\_N=8388608  
StarRandomAccess\_GUPs=0.00283447  
SingleRandomAccess\_GUPs=0.00404454  
STREAM\_VectorSize=3255208  
STREAM\_Threads=1  
StarSTREAM\_Copy=1.78375  
StarSTREAM\_Scale=1.74511  
StarSTREAM\_Add=1.97509  
StarSTREAM\_Triad=1.9761  
SingleSTREAM\_Copy=3.01614  
SingleSTREAM\_Scale=2.94039  
SingleSTREAM\_Add=3.31939  
SingleSTREAM\_Triad=3.31824  
FFT\_N=2097152

```

StarFFT_Gflops=0.450625
SingleFFT_Gflops=0.717585
MPIFFT_N=1073741824
MPIFFT_Gflops=45.1478
MPIFFT_maxErr=1.78836e-15
MaxPingPongLatency_usec=5.81145
RandomlyOrderedRingLatency_usec=17.4936
MinPingPongBandwidth_GBytes=0.195132
NaturallyOrderedRingBandwidth_GBytes=0.135169
RandomlyOrderedRingBandwidth_GBytes=0.0238855
MinPingPongLatency_usec=4.36604
AvgPingPongLatency_usec=4.99336
MaxPingPongBandwidth_GBytes=0.197295
AvgPingPongBandwidth_GBytes=0.196484
NaturallyOrderedRingLatency_usec=6.10352
FFTEblk=16
FFTEnp=8
FFTEl2size=1048576
M_OPENMP=-1
omp_get_num_threads=0
omp_get_max_threads=0
omp_get_num_procs=0
MemProc=-1
MemSpec=-1
MemVal=-1
MPIFFT_time0=3.09944e-06
MPIFFT_time1=0.915237
MPIFFT_time2=0.377161
MPIFFT_time3=0.862327
MPIFFT_time4=0.47812
MPIFFT_time5=0.916633
MPIFFT_time6=3.09944e-06
End of Summary section.
#####
End of HPC Challenge tests.
Current time (1182262782) is Tue Jun 19 10:19:42 2007

```

```
#####
```

## 6.b. *HPCC benchmark data for initial 2048 core configuration*

### 6.b.1. *HPCC benchmark data for N=70000*

```
#####
This is the DARPA/DOE HPC Challenge Benchmark version 1.0.0 October 2003
Produced by Jack Dongarra and Piotr Luszczek
Innovative Computing Laboratory
University of Tennessee Knoxville and Oak Ridge National Laboratory

```

```

See the source files for authors of specific codes.
Compiled on Jun 18 2007 at 11:44:38
Current time (1182266522) is Tue Jun 19 11:22:02 2007

```

```

Hostname: 's15c3b3.dim'
#####
=====
HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004
Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK
=====

```

```

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 : 70000  
NB : 200  
PMAP : Row-major process mapping  
P : 16  
Q : 32  
PFACT : Left  
NBMIN : 4  
NDIV : 2  
RFACT : Right  
BCAST : 2ringM  
DEPTH : 0  
SWAP : Mix (threshold = 64)  
L1 : transposed form  
U : transposed form  
EQUIL : yes  
ALIGN : 16 double precision words

-----  
- The matrix A is randomly generated for each test.  
- The following scaled residual checks will be computed:  
1)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N)$   
2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
- The relative machine precision (eps) is taken to be 1.110223e-16  
- Computational tests pass if scaled residuals are less than 16.0

Begin of PTRANS section.

M: 35000  
N: 35000  
MB: 200 100 200  
NB: 200 100 200  
P: 16  
Q: 32

	TIME	M	N	MB	NB	P	Q	TIME	CHECK	GB/s	RESID
WALL	35000	35000	200	200	16	32	0.81	PASSED	12.064	0.00	
CPU	35000	35000	200	200	16	32	0.82	PASSED	11.951	0.00	
WALL	35000	35000	100	100	16	32	0.71	PASSED	13.726	0.00	
CPU	35000	35000	100	100	16	32	0.73	PASSED	13.425	0.00	
WALL	35000	35000	200	200	16	32	0.82	PASSED	12.018	0.00	
CPU	35000	35000	200	200	16	32	0.82	PASSED	11.951	0.00	

Finished 3 tests, with the following results:  
3 tests completed and passed residual checks.  
0 tests completed and failed residual checks.  
0 tests skipped because of illegal input values.

END OF TESTS.

Current time (1182266528) is Tue Jun 19 11:22:08 2007

End of PTRANS section.

Begin of HPL section.

=====  
HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004  
Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK  
=====

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 : 70000  
 NB : 200  
 PMAP : Row-major process mapping  
 P : 16  
 Q : 32  
 PFACT : Left  
 NBMIN : 4  
 NDIV : 2  
 RFACT : Right  
 BCAST : 2ringM  
 DEPTH : 0  
 SWAP : Mix (threshold = 64)  
 L1 : transposed form  
 U : transposed form  
 EQUIL : yes  
 ALIGN : 16 double precision words

-----  
 The matrix A is randomly generated for each test.  
 -- The following scaled residual checks will be computed:  
 1)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N)$   
 2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 - 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
-----
WR03R2L4    70000  200   16   32          122.87         1.861e+03
=====
 $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N) = 0.0074097 \dots \text{PASSED}$ 
 $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty}) = 0.0100375 \dots \text{PASSED}$ 
 $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty}) = 0.0016702 \dots \text{PASSED}$ 
=====

```

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.

=====

Current time (1182266652) is Tue Jun 19 11:24:12 2007

End of HPL section.  
 Begin of StarDGEMM section.  
 Scaled residual: 0.00505038  
 Node(s) with error 0  
 Minimum Gflop/s 5.596380  
 Average Gflop/s 7.287612  
 Maximum Gflop/s 7.635199  
 Current time (1182266655) is Tue Jun 19 11:24:15 2007

End of StarDGEMM section.  
 Begin of SingleDGEMM section.  
 Node(s) with error 0  
 Node selected 402  
 Single DGEMM Gflop/s 8.067628  
 Current time (1182266657) is Tue Jun 19 11:24:17 2007

End of SingleDGEMM section.  
Begin of StarSTREAM section.

-----  
This system uses 8 bytes per DOUBLE PRECISION word.  
-----

Array size = 3190104, Offset = 0  
Total memory required = 0.0713 GB.  
Each test is run 10 times, but only  
the \*best\* time for each is used.

-----  
Your clock granularity/precision appears to be 1 microseconds.  
Each test below will take on the order of 34368 microseconds.  
(= 34368 clock ticks)

Increase the size of the arrays if this shows that  
you are not getting at least 20 clock ticks per test.

-----  
WARNING -- The above is only a rough guideline.  
For best results, please be sure you know the  
precision of your system timer.

-----  
Function           Rate (GB/s)   Avg time       Min time       Max time  
Copy:             1.0233       0.0500        0.0499        0.0501  
Scale:            1.0230       0.0500        0.0499        0.0503  
Add:              1.1475       0.0670        0.0667        0.0673  
Triad:            1.1906       0.0671        0.0643        0.0675  
-----

Results Comparison:

Expected : 3679149435468749824.000000 735829887093750016.000000  
981106516124999936.000000

Observed : 3679149435538703872.000000 735829887103518720.000000  
981106516135525632.000000

Solution Validates

-----  
Node(s) with error 0

Minimum Copy GB/s 0.992160  
Average Copy GB/s 1.029710  
Maximum Copy GB/s 1.086132  
Minimum Scale GB/s 0.988011  
Average Scale GB/s 1.030611  
Maximum Scale GB/s 1.078901  
Minimum Add GB/s 1.073509  
Average Add GB/s 1.162837  
Maximum Add GB/s 1.200585  
Minimum Triad GB/s 1.075087  
Average Triad GB/s 1.168802  
Maximum Triad GB/s 1.456752  
Current time (1182266659) is Tue Jun 19 11:24:19 2007

End of StarSTREAM section.  
Begin of SingleSTREAM section.

Node(s) with error 0  
Node selected 368  
Single STREAM Copy GB/s 3.020930  
Single STREAM Scale GB/s 2.946100  
Single STREAM Add GB/s 3.314271  
Single STREAM Triad GB/s 3.318587  
Current time (1182266660) is Tue Jun 19 11:24:20 2007

End of SingleSTREAM section.  
Begin of MPIRandomAccess section.  
Running on 512 processors (PowerofTwo)  
Total Main table size =  $2^{32}$  = 4294967296 words  
PE Main table size =  $2^{23}$  = 8388608 words/PE  
Default number of updates (RECOMMENDED) = 17179869184  
Number of updates EXECUTED = 9200124928 (for a TIME BOUND of 60.00 secs)  
CPU time used = 57.540000 seconds

Real time used = 57.549086 seconds  
0.159865701 Billion( $10^9$ ) Updates per second [GUP/s]  
0.000312238 Billion( $10^9$ ) Updates/PE per second [GUP/s]  
Verification: CPU time used = 23.180000 seconds  
Verification: Real time used = 23.601585 seconds  
Found 0 errors in 4294967296 locations (passed).  
Current time (1182266743) is Tue Jun 19 11:25:43 2007

End of MPIRandomAccess section.  
Begin of StarRandomAccess section.  
Main table size =  $2^{23}$  = 8388608 words  
Number of updates = 33554432  
CPU time used = 11.820000 seconds  
Real time used = 11.830897 seconds  
0.002836170 Billion( $10^9$ ) Updates per second [GUP/s]  
Found 0 errors in 8388608 locations (passed).  
Node(s) with error 0  
Minimum GUP/s 0.002805  
Average GUP/s 0.002836  
Maximum GUP/s 0.002885  
Current time (1182266767) is Tue Jun 19 11:26:07 2007

End of StarRandomAccess section.  
Begin of SingleRandomAccess section.  
Node(s) with error 0  
Node selected 475  
Single GUP/s 0.004057  
Current time (1182266783) is Tue Jun 19 11:26:23 2007

End of SingleRandomAccess section.  
Begin of MPIFFT section.  
Number of nodes: 512  
Vector size: 536870912  
Generation time: 0.178  
Tuning: 0.163  
Computing: 2.916  
Inverse FFT: 2.921  
 $\max(|x-x_0|)$ :  $1.717e-15$   
Current time (1182266790) is Tue Jun 19 11:26:30 2007

End of MPIFFT section.  
Begin of StarFFT section.  
Vector size: 2097152  
Generation time: 0.357  
Tuning: 0.001  
Computing: 0.483  
Inverse FFT: 0.539  
 $\max(|x-x_0|)$ :  $1.617e-15$   
Node(s) with error 0  
Minimum Gflop/s 0.412050  
Average Gflop/s 0.450655  
Maximum Gflop/s 0.466624  
Current time (1182266792) is Tue Jun 19 11:26:32 2007

End of StarFFT section.  
Begin of SingleFFT section.  
Node(s) with error 0  
Node selected 453  
Single FFT Gflop/s 0.707194  
Current time (1182266793) is Tue Jun 19 11:26:33 2007

End of SingleFFT section.  
Begin of LatencyBandwidth section.

-----  
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart  
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany



Details - level 2

-----

MPI\_Wtime granularity.

Max. MPI\_Wtick is 0.000001 sec

wtick is set to 0.000001 sec

Message Length: 8

Latency min / avg / max: 0.005260 / 0.005260 / 0.005260 msecs  
Bandwidth min / avg / max: 1.521 / 1.521 / 1.521 MByte/s

MPI\_Wtime granularity is ok.

message size: 8  
max time : 10.000000 secs  
latency for msg: 0.005260 msecs  
estimation for ping pong: 0.473410 msecs  
max number of ping pong pairs = 21123  
max client pings = max server pongs = 145  
stride for latency = 5

Message Length: 8

Latency min / avg / max: 0.000998 / 0.005111 / 0.005379 msecs  
Bandwidth min / avg / max: 1.487 / 1.600 / 8.013 MByte/s

Message Length: 2000000

Latency min / avg / max: 10.195971 / 10.195971 / 10.195971 msecs  
Bandwidth min / avg / max: 196.156 / 196.156 / 196.156 MByte/s

MPI\_Wtime granularity is ok.

message size: 2000000  
max time : 30.000000 secs  
latency for msg: 10.195971 msecs  
estimation for ping pong: 81.567764 msecs  
max number of ping pong pairs = 367  
max client pings = max server pongs = 19  
stride for latency = 29

Message Length: 2000000

Latency min / avg / max: 10.139465 / 10.179064 / 10.231495 msecs  
Bandwidth min / avg / max: 195.475 / 196.482 / 197.249 MByte/s

Message Size: 8 Byte

Natural Order Latency: 0.005603 msec  
Natural Order Bandwidth: 1.427848 MB/s  
Avg Random Order Latency: 0.017202 msec  
Avg Random Order Bandwidth: 0.465049 MB/s

Message Size: 2000000 Byte

Natural Order Latency: 17.032743 msec  
Natural Order Bandwidth: 117.420903 MB/s  
Avg Random Order Latency: 66.029662 msec  
Avg Random Order Bandwidth: 30.289417 MB/s

Execution time (wall clock) = 56.667 sec on 512 processes  
- for cross ping\_pong latency = 5.185 sec  
- for cross ping\_pong bandwidth = 25.942 sec  
- for ring latency = 0.276 sec  
- for ring bandwidth = 25.264 sec

-----  
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart  
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany

Major Benchmark results:

-----

Max Ping Pong Latency: 0.005379 msecs  
Randomly Ordered Ring Latency: 0.017202 msecs  
Min Ping Pong Bandwidth: 195.474857 MB/s

Naturally Ordered Ring Bandwidth: 117.420903 MB/s  
Randomly Ordered Ring Bandwidth: 30.289417 MB/s

-----  
Detailed benchmark results:

Ping Pong:

Latency min / avg / max: 0.000998 / 0.005111 / 0.005379 msecs  
Bandwidth min / avg / max: 195.475 / 196.482 / 197.249 MByte/s

Ring:

On naturally ordered ring: latency= 0.005603 msec, bandwidth= 117.420903 MB/s  
On randomly ordered ring: latency= 0.017202 msec, bandwidth= 30.289417 MB/s

-----  
Benchmark conditions:

The latency measurements were done with 8 bytes  
The bandwidth measurements were done with 2000000 bytes  
The ring communication was done in both directions on 512 processes  
The Ping Pong measurements were done on  
- 10609 pairs of processes for latency benchmarking, and  
- 324 pairs of processes for bandwidth benchmarking,  
out of 512\*(512-1) = 261632 possible combinations on 512 processes.  
(1 MB/s = 10\*\*6 byte/sec)

-----  
Current time (1182266850) is Tue Jun 19 11:27:30 2007

End of LatencyBandwidth section.

Begin of Summary section.

VersionMajor=1  
VersionMinor=0  
VersionMicro=0  
VersionRelease=b  
LANG=C  
Success=1  
sizeof\_char=1  
sizeof\_short=2  
sizeof\_int=4  
sizeof\_long=8  
sizeof\_void\_ptr=8  
sizeof\_size\_t=8  
sizeof\_float=4  
sizeof\_double=8  
sizeof\_s64Int=8  
sizeof\_u64Int=8  
CommWorldProcs=512  
MPI\_Wtick=9.536743e-07  
HPL\_Tflops=1.86107  
HPL\_time=122.873  
HPL\_eps=1.11022e-16  
HPL\_RnormI=1.01772e-09  
HPL\_Anorm1=17673.5  
HPL\_AnormI=17648.8  
HPL\_Xnorm1=51674.1  
HPL\_XnormI=4.44249  
HPL\_N=70000  
HPL\_NB=200  
HPL\_nprow=16  
HPL\_npcol=32  
HPL\_depth=0  
HPL\_nbddiv=2  
HPL\_nbmin=4  
HPL\_cpfact=L  
HPL\_cract=R  
HPL\_ctop=3  
HPL\_order=R

HPL\_dMACH\_EPS=1.110223e-16  
HPL\_dMACH\_SFMIN=2.225074e-308  
HPL\_dMACH\_BASE=2.000000e+00  
HPL\_dMACH\_PREC=2.220446e-16  
HPL\_dMACH\_MLEN=5.300000e+01  
HPL\_dMACH\_RND=1.000000e+00  
HPL\_dMACH\_EMIN=-1.021000e+03  
HPL\_dMACH\_RMIN=2.225074e-308  
HPL\_dMACH\_EMAX=1.024000e+03  
HPL\_dMACH\_RMAX=1.797693e+308  
HPL\_sMACH\_EPS=5.960464e-08  
HPL\_sMACH\_SFMIN=1.175494e-38  
HPL\_sMACH\_BASE=2.000000e+00  
HPL\_sMACH\_PREC=1.192093e-07  
HPL\_sMACH\_MLEN=2.400000e+01  
HPL\_sMACH\_RND=1.000000e+00  
HPL\_sMACH\_EMIN=-1.250000e+02  
HPL\_sMACH\_RMIN=1.175494e-38  
HPL\_sMACH\_EMAX=1.280000e+02  
HPL\_sMACH\_RMAX=3.402823e+38  
dweeps=1.110223e-16  
sweps=5.960464e-08  
HPLMaxProcs=512  
HPLMinProcs=512  
DGEMM\_N=1546  
StarDGEMM\_Gflops=7.28761  
SingleDGEMM\_Gflops=8.06763  
PTRANS\_GBs=13.7264  
PTRANS\_time=0.713952  
PTRANS\_residual=0  
PTRANS\_n=35000  
PTRANS\_nb=100  
PTRANS\_nproW=16  
PTRANS\_npcol=32  
MPIRandomAccess\_N=4294967296  
MPIRandomAccess\_time=57.5491  
MPIRandomAccess\_CheckTime=23.6016  
MPIRandomAccess\_Errors=0  
MPIRandomAccess\_ErrorsFraction=0  
MPIRandomAccess\_ExeUpdates=9200124928  
MPIRandomAccess\_GUPs=0.159866  
MPIRandomAccess\_TimeBound=60  
RandomAccess\_N=8388608  
StarRandomAccess\_GUPs=0.00283563  
SingleRandomAccess\_GUPs=0.00405748  
STREAM\_VectorSize=3190104  
STREAM\_Threads=1  
StarSTREAM\_Copy=1.02971  
StarSTREAM\_Scale=1.03061  
StarSTREAM\_Add=1.16284  
StarSTREAM\_Triad=1.1688  
SingleSTREAM\_Copy=3.02093  
SingleSTREAM\_Scale=2.9461  
SingleSTREAM\_Add=3.31427  
SingleSTREAM\_Triad=3.31859  
FFT\_N=2097152  
StarFFT\_Gflops=0.450655  
SingleFFT\_Gflops=0.707194  
MPIFFT\_N=536870912  
MPIFFT\_Gflops=26.6959  
MPIFFT\_maxErr=1.71659e-15  
MaxPingPongLatency\_usec=5.37932  
RandomlyOrderedRingLatency\_usec=17.2025  
MinPingPongBandwidth\_GBytes=0.195475  
NaturallyOrderedRingBandwidth\_GBytes=0.117421  
RandomlyOrderedRingBandwidth\_GBytes=0.0302894  
MinPingPongLatency\_usec=0.998378

```

AvgPingPongLatency_usec=5.1106
MaxPingPongBandwidth_GBytes=0.197249
AvgPingPongBandwidth_GBytes=0.196482
NaturallyOrderedRingLatency_usec=5.60284
FFTEblk=16
FFTEnp=8
FFTEl2size=1048576
M_OPENMP=-1
omp_get_num_threads=0
omp_get_max_threads=0
omp_get_num_procs=0
MemProc=-1
MemSpec=-1
MemVal=-1
MPIFFT_time0=4.05312e-06
MPIFFT_time1=0.747922
MPIFFT_time2=0.259638
MPIFFT_time3=0.683326
MPIFFT_time4=0.474093
MPIFFT_time5=0.725643
MPIFFT_time6=3.09944e-06
End of Summary section.
#####
End of HPC Challenge tests.
Current time (1182266850) is Tue Jun 19 11:27:30 2007

```

**6.b.2. HPC benchmark data for N=10000**

```

#####
This is the DARPA/DOE HPC Challenge Benchmark version 1.0.0 October 2003
Produced by Jack Dongarra and Piotr Luszczek
Innovative Computing Laboratory
University of Tennessee Knoxville and Oak Ridge National Laboratory

See the source files for authors of specific codes.
Compiled on Jun 18 2007 at 11:44:38
Current time (1182266961) is Tue Jun 19 11:29:21 2007

```

```

Hostname: 'slc1b1.dim'
#####
=====
HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004
Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK
=====

```

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       : 100000
NB      : 200
PMAP    : Row-major process mapping
P       : 32
Q       : 64
PFACT   : Left
NBMIN   : 4
NDIV    : 2
RFACT   : Right
BCAST   : 2ringM

```

DEPTH : 0  
 SWAP : Mix (threshold = 64)  
 L1 : transposed form  
 U : transposed form  
 EQUIL : yes  
 ALIGN : 16 double precision words

-----  
 - The matrix A is randomly generated for each test.  
 - The following scaled residual checks will be computed:  
 1)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * N)$   
 2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 - The relative machine precision (eps) is taken to be 1.110223e-16  
 - Computational tests pass if scaled residuals are less than 16.0

Begin of PTRANS section.

M: 50000  
 N: 50000  
 MB: 200 100 200  
 NB: 200 100 200  
 P: 32  
 Q: 64

TIME	M	N	MB	NB	P	Q	TIME	CHECK	GB/s	RESID
WALL	50000	50000	200	200	32	64	0.53	PASSED	37.462	0.00
CPU	50000	50000	200	200	32	64	0.54	PASSED	37.037	0.00
WALL	50000	50000	100	100	32	64	0.54	PASSED	36.716	0.00
CPU	50000	50000	100	100	32	64	0.55	PASSED	36.364	0.00
WALL	50000	50000	200	200	32	64	0.53	PASSED	37.493	0.00
CPU	50000	50000	200	200	32	64	0.55	PASSED	36.364	0.00

Finished 3 tests, with the following results:  
 3 tests completed and passed residual checks.  
 0 tests completed and failed residual checks.  
 0 tests skipped because of illegal input values.

END OF TESTS.  
 Current time (1182266975) is Tue Jun 19 11:29:35 2007

End of PTRANS section.

Begin of HPL section.

=====

HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004  
 Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK  
 =====

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 : 100000  
 NB : 200  
 PMAP : Row-major process mapping  
 P : 32  
 Q : 64  
 PFACT : Left  
 NBMIN : 4  
 NDIV : 2

```

RFACT : Right
BCAST : 2ringM
DEPTH : 0
SWAP : Mix (threshold = 64)
L1 : transposed form
U : transposed form
EQUIL : yes
ALIGN : 16 double precision words

```

```

-----
- The matrix A is randomly generated for each test.
- The following scaled residual checks will be computed:
  1)  $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_1 * N}$ 
  2)  $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_1 * \|x\|_1}$ 
  3)  $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_{\infty} * \|x\|_{\infty}}$ 
- The relative machine precision (eps) is taken to be 1- Computational tests
pass if scaled residuals are less than 16.0

```

```

=====
T/V                N      NB      P      Q                Time                Gflops
-----
WR03R2L4          100000   200     32     64                129.38                5.153e+03
=====
 $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_1 * N} = 0.0162180$  ..... PASSED
 $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_1 * \|x\|_1} = 0.0109091$  ..... PASSED
 $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_{\infty} * \|x\|_{\infty}} = 0.0019615$  ..... 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.

```

```

=====
Current time (1182267105) is Tue Jun 19 11:31:45 2007

```

```

End of HPL section.
Begin of StarDGEMM section.
Scaled residual: 0.00593874
Node(s) with error 0
Minimum Gflop/s 4.424290
Average Gflop/s 7.079863
Maximum Gflop/s 7.642500
Current time (1182267106) is Tue Jun 19 11:31:46 2007

```

```

End of StarDGEMM section.
Begin of SingleDGEMM section.
Node(s) with error 0
Node selected 1587
Single DGEMM Gflop/s 7.912201
Current time (1182267107) is Tue Jun 19 11:31:47 2007

```

```

End of SingleDGEMM section.
Begin of StarSTREAM section.

```

```

-----
This system uses 8 bytes per DOUBLE PRECISION word.

```

```

-----
Array size = 1627604, Offset = 0
Total memory required = 0.0364 GB.
Each test is run 10 times, but only
the *best* time for each is used.

```

```

-----
Your clock granularity/precision appears to be 1 microseconds.
Each test below will take on the order of 17235 microseconds.

```

(= 17235 clock ticks)

Increase the size of the arrays if this shows that you are not getting at least 20 clock ticks per test.

-----  
WARNING -- The above is only a rough guideline.  
For best results, please be sure you know the precision of your system timer.  
-----

Function	Rate (GB/s)	Avg time	Min time	Max time
Copy:	1.0152	0.0259	0.0257	0.0261
.110223e-16				
Scale:	1.0667	0.0245	0.0244	0.0247
Add:	1.1655	0.0338	0.0335	0.0341
Triad:	1.2319	0.0338	0.0317	0.0343

-----  
Results Comparison:  
Expected : 1877116964765625088.000000 375423392953124992.000000  
500564523937500032.000000  
Observed : 1877116964762494976.000000 375423392953518720.000000  
500564523937500032.000000  
Solution Validates  
-----

Node(s) with error 0  
Minimum Copy GB/s 0.953661  
Average Copy GB/s 1.020977  
Maximum Copy GB/s 1.196598  
Minimum Scale GB/s 0.987395  
Average Scale GB/s 1.031436  
Maximum Scale GB/s 1.385633  
Minimum Add GB/s 1.054997  
Average Add GB/s 1.143028  
Maximum Add GB/s 1.461643  
Minimum Triad GB/s 1.074565  
Average Triad GB/s 1.153736  
Maximum Triad GB/s 2.150413  
Current time (1182267109) is Tue Jun 19 11:31:49 2007

End of StarSTREAM section.  
Begin of SingleSTREAM section.  
Node(s) with error 0  
Node selected 2028  
Single STREAM Copy GB/s 2.923391  
Single STREAM Scale GB/s 3.046514  
Single STREAM Add GB/s 3.180433  
Single STREAM Triad GB/s 3.170646  
Current time (1182267109) is Tue Jun 19 11:31:49 2007

End of SingleSTREAM section.  
Begin of MPIRandomAccess section.  
Running on 2048 processors (PowerofTwo)  
Total Main table size =  $2^{33}$  = 8589934592 words  
PE Main table size =  $2^{22}$  = 4194304 words/PE  
Default number of updates (RECOMMENDED) = 34359738368  
Number of updates EXECUTED = 14134075392 (for a TIME BOUND of 60.00 secs)  
CPU time used = 58.090000 seconds  
Real time used = 58.085687 seconds  
0.243331467 Billion( $10^9$ ) Updates per second [GUP/s]  
0.000118814 Billion( $10^9$ ) Updates/PE per second [GUP/s]  
Verification: CPU time used = 32.160000 seconds  
Verification: Real time used = 33.033619 seconds  
Found 0 errors in 8589934592 locations (passed).  
Current time (1182267202) is Tue Jun 19 11:33:22 2007

End of MPIRandomAccess section.  
Begin of StarRandomAccess section.  
Main table size =  $2^{22}$  = 4194304 words  
Number of updates = 16777216

CPU time used = 5.280000 seconds  
Real time used = 5.280341 seconds  
0.003177298 Billion( $10^9$ ) Updates per second [GUP/s]  
Found 0 errors in 4194304 locations (passed).  
Node(s) with error 0  
Minimum GUP/s 0.003133  
Average GUP/s 0.003171  
Maximum GUP/s 0.003232  
Current time (1182267213) is Tue Jun 19 11:33:33 2007

End of StarRandomAccess section.  
Begin of SingleRandomAccess section.  
Node(s) with error 0  
Node selected 1563  
Single GUP/s 0.004696  
Current time (1182267220) is Tue Jun 19 11:33:40 2007

End of SingleRandomAccess section.  
Begin of MPIFFT section.  
Number of nodes: 2048  
Vector size: 1073741824  
Generation time: 0.089  
Tuning: 0.081  
Computing: 2.119  
Inverse FFT: 2.076  
max(|x-x0|): 1.755e-15  
Current time (1182267224) is Tue Jun 19 11:33:44 2007

End of MPIFFT section.  
Begin of StarFFT section.  
Vector size: 1048576  
Generation time: 0.178  
Tuning: 0.001  
Computing: 0.218  
Inverse FFT: 0.238  
max(|x-x0|): 1.590e-15  
Node(s) with error 0  
Minimum Gflop/s 0.410551  
Average Gflop/s 0.458268  
Maximum Gflop/s 0.490154  
Current time (1182267225) is Tue Jun 19 11:33:45 2007

End of StarFFT section.  
Begin of SingleFFT section.  
Node(s) with error 0  
Node selected 1143  
Single FFT Gflop/s 0.722309  
Current time (1182267226) is Tue Jun 19 11:33:46 2007

End of SingleFFT section.  
Begin of LatencyBandwidth section.

-----  
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart  
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany

Details - level 2  
-----

MPI\_Wtime granularity.  
Max. MPI\_Wtick is 0.000001 sec  
wtick is set to 0.000001 sec

Message Length: 8  
Latency min / avg / max: 0.005439 / 0.005439 / 0.005439 msecs  
Bandwidth min / avg / max: 1.471 / 1.471 / 1.471 MByte/s



```

MPI_Wtime granularity is ok.
message size:                               8
max time :                                  10.000000 secs
latency for msg:                             0.005439 msecs
estimation for ping pong:                     0.489503 msecs
max number of ping pong pairs =               20428
max client pings = max server pongs =         142
stride for latency =                          17
Message Length: 8
Latency  min / avg / max:  0.004306 /  0.005327 /  0.005990 msecs
Bandwidth min / avg / max:  1.335 /    1.508 /    1.858 MByte/s

```

```

Message Length: 2000000
Latency  min / avg / max:  10.218978 /  10.218978 /  10.218978 msecs
Bandwidth min / avg / max:  195.714 /   195.714 /   195.714 MByte/s

```

```

MPI_Wtime granularity is ok.
message size:                               2000000
max time :                                  30.000000 secs
latency for msg:                             10.218978 msecs
estimation for ping pong:                     81.751823 msecs
max number of ping pong pairs =               366
max client pings = max server pongs =         19
stride for latency =                          109
Message Length: 2000000
Latency  min / avg / max:  10.151982 /  10.201659 /  10.652542 msecs
Bandwidth min / avg / max:  187.749 /   196.053 /   197.006 MByte/s

```

```

Message Size:                               8 Byte
Natural Order Latency:                       0.006413 msec
Natural Order Bandwidth:                     1.247377 MB/s
Avg Random Order Latency:                    0.018138 msec
Avg Random Order Bandwidth:                  0.441071 MB/s

```

```

Message Size:                               2000000 Byte
Natural Order Latency:                       18.761754 msec
Natural Order Bandwidth:                     106.599841 MB/s
Avg Random Order Latency:                    90.116342 msec
Avg Random Order Bandwidth:                  22.193533 MB/s

```

```

Execution time (wall clock) = 71.540 sec on 2048 processes
- for cross ping_pong latency = 7.573 sec
- for cross ping_pong bandwidth = 29.036 sec
- for ring latency = 1.127 sec
- for ring bandwidth = 33.804 sec

```

```

-----
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany
Major Benchmark results:
-----

```

```

Max Ping Pong Latency:                       0.005990 msecs
Randomly Ordered Ring Latency:               0.018138 msecs
Min Ping Pong Bandwidth:                     187.748612 MB/s
Naturally Ordered Ring Bandwidth:           106.599841 MB/s
Randomly Ordered Ring Bandwidth:            22.193533 MB/s

```

```

-----
Detailed benchmark results:
Ping Pong:
Latency  min / avg / max:  0.004306 /  0.005327 /  0.005990 msecs
Bandwidth min / avg / max:  187.749 /   196.053 /   197.006 MByte/s
Ring:
On naturally ordered ring: latency=          0.006413 msec, bandwidth= 106.599841 MB/s
On randomly ordered ring: latency=          0.018138 msec, bandwidth= 22.193533 MB/s

```

-----  
Benchmark conditions:

The latency measurements were done with 8 bytes  
The bandwidth measurements were done with 2000000 bytes  
The ring communication was done in both directions on 2048 processes  
The Ping Pong measurements were done on  
- 14641 pairs of processes for latency benchmarking, and  
- 361 pairs of processes for bandwidth benchmarking,  
out of  $2048 \times (2048 - 1) = 4192256$  possible combinations on 2048 processes.  
(1 MB/s =  $10^6$  byte/sec)

-----  
Current time (1182267297) is Tue Jun 19 11:34:57 2007

End of LatencyBandwidth section.

Begin of Summary section.

VersionMajor=1  
VersionMinor=0  
VersionMicro=0  
VersionRelease=b  
LANG=C  
Success=1  
sizeof\_char=1  
sizeof\_short=2  
sizeof\_int=4  
sizeof\_long=8  
sizeof\_void\_ptr=8  
sizeof\_size\_t=8  
sizeof\_float=4  
sizeof\_double=8  
sizeof\_s64Int=8  
sizeof\_u64Int=8  
CommWorldProcs=2048  
MPI\_Wtick=9.536743e-07  
HPL\_Tflops=5.153  
HPL\_time=129.377  
HPL\_eps=1.11022e-16  
HPL\_RnormI=4.53557e-09  
HPL\_Anorm1=25189.8  
HPL\_AnormI=25157.5  
HPL\_Xnorm1=148665  
HPL\_XnormI=8.2789  
HPL\_N=100000  
HPL\_NB=200  
HPL\_nprow=32  
HPL\_npcol=64  
HPL\_depth=0  
HPL\_nbdiv=2  
HPL\_nbmin=4  
HPL\_cpfact=L  
HPL\_crfact=R  
HPL\_ctop=3  
HPL\_order=R  
HPL\_dMACH\_EPS=1.110223e-16  
HPL\_dMACH\_SFMIN=2.225074e-308  
HPL\_dMACH\_BASE=2.000000e+00  
HPL\_dMACH\_PREC=2.220446e-16  
HPL\_dMACH\_MLEN=5.300000e+01  
HPL\_dMACH\_RND=1.000000e+00  
HPL\_dMACH\_EMIN=-1.021000e+03  
HPL\_dMACH\_RMIN=2.225074e-308  
HPL\_dMACH\_EMAX=1.024000e+03  
HPL\_dMACH\_RMAX=1.797693e+308  
HPL\_sMACH\_EPS=5.960464e-08  
HPL\_sMACH\_SFMIN=1.175494e-38

HPL\_sMACH\_BASE=2.000000e+00  
HPL\_sMACH\_PREC=1.192093e-07  
HPL\_sMACH\_MLEN=2.400000e+01  
HPL\_sMACH\_RND=1.000000e+00  
HPL\_sMACH\_EMIN=-1.250000e+02  
HPL\_sMACH\_RMIN=1.175494e-38  
HPL\_sMACH\_EMAX=1.280000e+02  
HPL\_sMACH\_RMAX=3.402823e+38  
dweeps=1.110223e-16  
sweps=5.960464e-08  
HPLMaxProcs=2048  
HPLMinProcs=2048  
DGEMM\_N=1104  
StarDGEMM\_Gflops=7.07986  
SingleDGEMM\_Gflops=7.9122  
PTRANS\_GBs=37.4932  
PTRANS\_time=0.53343  
PTRANS\_residual=0  
PTRANS\_n=50000  
PTRANS\_nb=200  
PTRANS\_nprow=32  
PTRANS\_npcol=64  
MPIRandomAccess\_N=8589934592  
MPIRandomAccess\_time=58.0857  
MPIRandomAccess\_CheckTime=33.0336  
MPIRandomAccess\_Errors=0  
MPIRandomAccess\_ErrorsFraction=0  
MPIRandomAccess\_ExeUpdates=14134075392  
MPIRandomAccess\_GUPs=0.243331  
MPIRandomAccess\_TimeBound=60  
RandomAccess\_N=4194304  
StarRandomAccess\_GUPs=0.00317136  
SingleRandomAccess\_GUPs=0.00469598  
STREAM\_VectorSize=1627604  
STREAM\_Threads=1  
StarSTREAM\_Copy=1.02098  
StarSTREAM\_Scale=1.03144  
StarSTREAM\_Add=1.14303  
StarSTREAM\_Triad=1.15374  
SingleSTREAM\_Copy=2.92339  
SingleSTREAM\_Scale=3.04651  
SingleSTREAM\_Add=3.18043  
SingleSTREAM\_Triad=3.17065  
FFT\_N=1048576  
StarFFT\_Gflops=0.458268  
SingleFFT\_Gflops=0.722309  
MPIFFT\_N=1073741824  
MPIFFT\_Gflops=75.9955  
MPIFFT\_maxErr=1.75542e-15  
MaxPingPongLatency\_usec=5.99027  
RandomlyOrderedRingLatency\_usec=18.1377  
MinPingPongBandwidth\_GBytes=0.187749  
NaturallyOrderedRingBandwidth\_GBytes=0.1066  
RandomlyOrderedRingBandwidth\_GBytes=0.0221935  
MinPingPongLatency\_usec=4.30644  
AvgPingPongLatency\_usec=5.32659  
MaxPingPongBandwidth\_GBytes=0.197006  
AvgPingPongBandwidth\_GBytes=0.196053  
NaturallyOrderedRingLatency\_usec=6.41346  
FFTEblk=16  
FFTEnp=8  
FFTEl2size=1048576  
M\_OPENMP=-1  
omp\_get\_num\_threads=0  
omp\_get\_max\_threads=0  
omp\_get\_num\_procs=0  
MemProc=-1

```

MemSpec=-1
MemVal=-1
MPIFFT_time0=2.86102e-06
MPIFFT_time1=0.524337
MPIFFT_time2=0.1812
MPIFFT_time3=0.556872
MPIFFT_time4=0.237667
MPIFFT_time5=0.608035
MPIFFT_time6=2.86102e-06
End of Summary section.
#####
End of HPC Challenge tests.
Current time (1182267297) is Tue Jun 19 11:34:57 2007
#####

```

### 6.b.3. HPC benchmark data for N=600000

```

#####
This is the DARPA/DOE HPC Challenge Benchmark version 1.0.0 October 2003
Produced by Jack Dongarra and Piotr Luszczek
Innovative Computing Laboratory
University of Tennessee Knoxville and Oak Ridge National Laboratory

```

```

See the source files for authors of specific codes.
Compiled on May 10 2007 at 14:49:43
Current time (1180068203) is Fri May 25 00:43:23 2007

```

```

Hostname: 's11c1b2'

```

```

#####
=====
HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004
Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK
=====

```

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       : 600000
NB      : 200
PMAP    : Row-major process mapping
P       : 30
Q       : 68
PFACT   : Left
NBMIN   : 4
NDIV    : 2
RFACT   : Right
BCAST   : 2ringM
DEPTH   : 0
SWAP    : Mix (threshold = 64)
L1      : transposed form
U       : transposed form
EQUIL   : yes
ALIGN   : 16 double precision words

```

-----

- The matrix A is randomly generated for each test.
- The following scaled residual checks will be computed:
  - 1)  $\|Ax-b\|_{\infty} / (\text{eps} * \|A\|_1 * N)$

2)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$   
 3)  $\frac{\|Ax-b\|_{\infty}}{\|A\|_{\infty}} / (\text{eps} * \|A\|_{\infty} * \|x\|_{\infty})$

- The relative machine precision (eps) is taken to be 1.110223e-16  
 - Computational tests pass if scaled residuals are less than 16.0

Begin of PTRANS section.

M: 300000  
 N: 300000  
 MB: 200 100 200  
 NB: 200 100 200  
 P: 30  
 Q: 68

	TIME	M	N	MB	NB	P	Q	TIME	CHECK	GB/s	RESID
WALL	300000	300000	300000	200	200	30	68	31.22	PASSED	23.062	0.00
CPU	300000	300000	300000	200	200	30	68	31.24	PASSED	23.047	0.00
WALL	300000	300000	300000	100	100	30	68	17.66	PASSED	40.765	0.00
CPU	300000	300000	300000	100	100	30	68	17.69	PASSED	40.701	0.00
WALL	300000	300000	300000	200	200	30	68	31.18	PASSED	23.095	0.00
CPU	300000	300000	300000	200	200	30	68	31.22	PASSED	23.062	0.00

Finished 3 tests, with the following results:  
 3 tests completed and passed residual checks.  
 0 tests completed and failed residual checks.  
 0 tests skipped because of illegal input values.

END OF TESTS.  
 Current time (1180068420) is Fri May 25 00:47:00 2007  
 End of PTRANS section.

Begin of HPL section.

=====  
 HPLinpack 1.0a -- High-Performance Linpack benchmark -- January 20, 2004  
 Written by A. Petitet and R. Clint Whaley, Innovative Computing Labs., UTK  
 =====

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 : 600000  
 NB : 200  
 PMAP : Row-major process mapping  
 P : 30  
 Q : 68  
 PFACT : Left  
 NBMIN : 4  
 NDIV : 2  
 RFACT : Right  
 BCAST : 2ringM  
 DEPTH : 0  
 SWAP : Mix (threshold = 64)  
 L1 : transposed form  
 U : transposed form  
 EQUIL : yes  
 ALIGN : 16 double precision words

-----  
 - The matrix A is randomly generated for each test.  
 - The following scaled residual checks will be computed:

- 1)  $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_1 * N}$
- 2)  $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_1 * \|x\|_1}$
- 3)  $\frac{\|Ax-b\|_{\infty}}{\epsilon * \|A\|_{\infty} * \|x\|_{\infty}}$

- 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
WR03R2L4	600000	200	30	68	10641.34	1.353e+04

```
=====
```

$\frac{\ Ax-b\ _{\infty}}{\epsilon * \ A\ _1 * N}$ =	0.0099666	.....	PASSED
$\frac{\ Ax-b\ _{\infty}}{\epsilon * \ A\ _1 * \ x\ _1}$ =	0.0066616	.....	PASSED
$\frac{\ Ax-b\ _{\infty}}{\epsilon * \ A\ _{\infty} * \ x\ _{\infty}}$ =	0.0011291	.....	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.

```
=====
```

Current time (1180079078) is Fri May 25 03:44:38 2007  
 End of HPL section.

Begin of StarDGEMM section.

Scaled residual: 0.00242414  
 Node(s) with error 0  
 Minimum Gflop/s 6.792508  
 Average Gflop/s 8.268927  
 Maximum Gflop/s 8.319971  
 Current time (1180079189) is Fri May 25 03:46:29 2007

End of StarDGEMM section.

Begin of SingleDGEMM section.

Node(s) with error 0  
 Node selected 719  
 Single DGEMM Gflop/s 8.494016  
 Current time (1180079284) is Fri May 25 03:48:04 2007

End of SingleDGEMM section.

Begin of StarSTREAM section.

-----  
 This system uses 8 bytes per DOUBLE PRECISION word.  
 -----

Array size = 58823529, Offset = 0  
 Total memory required = 1.3148 GB.  
 Each test is run 10 times, but only  
 the \*best\* time for each is used.  
 -----

Your clock granularity/precision appears to be 1 microseconds.  
 Each test below will take on the order of 630958 microseconds.  
 (= 630958 clock ticks)  
 Increase the size of the arrays if this shows that

you are not getting at least 20 clock ticks per test.

-----  
WARNING -- The above is only a rough guideline.  
For best results, please be sure you know the  
precision of your system timer.  
-----

Function	Rate (GB/s)	Avg time	Min time	Max time
Copy:	1.0377	0.9083	0.9070	0.9100
Scale:	1.0497	0.9008	0.8966	0.9028
Add:	1.1782	1.2023	1.1982	1.2069
Triad:	1.1941	1.1958	1.1823	1.2006

-----  
Results Comparison:

Expected : 67841221951582027776.000000 13568244390316406784.000000  
18090992520421875712.000000  
Observed : 67841221942089768960.000000 13568244391914422272.000000  
18090992517186793472.000000

Solution Validates

-----  
Node(s) with error 0  
Minimum Copy GB/s 1.002325  
Average Copy GB/s 1.039966  
Maximum Copy GB/s 1.119272  
Minimum Scale GB/s 1.039187  
Average Scale GB/s 1.057497  
Maximum Scale GB/s 1.113818  
Minimum Add GB/s 1.156317  
Average Add GB/s 1.176485  
Maximum Add GB/s 1.195994  
Minimum Triad GB/s 1.169383  
Average Triad GB/s 1.210038  
Maximum Triad GB/s 1.327515  
Current time (1180079330) is Fri May 25 03:48:50 2007

End of StarSTREAM section.

Begin of SingleSTREAM section.

Node(s) with error 0  
Node selected 1806  
Single STREAM Copy GB/s 2.959842  
Single STREAM Scale GB/s 3.050984  
Single STREAM Add GB/s 3.318012  
Single STREAM Triad GB/s 3.312121  
Current time (1180079348) is Fri May 25 03:49:08 2007

End of SingleSTREAM section.

Begin of MPIRandomAccess section.

Running on 2040 processors  
Total Main table size = 238 = 274877906944 words  
PE Main table size = (238)/2040 = 134744073 words/PE MAX  
Default number of updates (RECOMMENDED) = 1099511627776  
Number of updates EXECUTED = 15331277280 (for a TIME BOUND of 2660.33 secs)  
CPU time used = 61.370000 seconds  
Real time used = 61.405342 seconds  
0.249673348 Billion(109) Updates per second [GUP/s]

0.000122389 Billion(109) Updates/PE per second [GUP/s]  
Verification: CPU time used = 32.340000 seconds  
Verification: Real time used = 33.676471 seconds  
Found 0 errors in 274877906944 locations (passed).  
Current time (1180079488) is Fri May 25 03:51:28 2007

End of MPIRandomAccess section.

Begin of StarRandomAccess section.

Main table size = 227 = 134217728 words  
Number of updates = 536870912  
CPU time used = 211.780000 seconds  
Real time used = 211.805222 seconds  
0.002534739 Billion(109) Updates per second [GUP/s]  
Found 0 errors in 134217728 locations (passed).  
Node(s) with error 0  
Minimum GUP/s 0.002520  
Average GUP/s 0.002536  
Maximum GUP/s 0.002540  
Current time (1180079912) is Fri May 25 03:58:32 2007

End of StarRandomAccess section.

Begin of SingleRandomAccess section.

Node(s) with error 0  
Node selected 1960  
Single GUP/s 0.003517  
Current time (1180080218) is Fri May 25 04:03:38 2007

End of SingleRandomAccess section.

Begin of MPIFFT section.

Number of nodes: 1024  
Vector size: 17179869184  
Generation time: 2.846  
Tuning: 2.592  
Computing: 43.377  
Inverse FFT: 44.124  
max(|x-x0|): 2.220e-15  
Current time (1180080317) is Fri May 25 04:05:17 2007

End of MPIFFT section.

Begin of StarFFT section.

Vector size: 33554432  
Generation time: 5.694  
Tuning: 0.003  
Computing: 10.507  
Inverse FFT: 11.355  
max(|x-x0|): 2.095e-15  
Node(s) with error 0  
Minimum Gflop/s 0.375156  
Average Gflop/s 0.399146  
Maximum Gflop/s 0.416085  
Current time (1180080352) is Fri May 25 04:05:52 2007

End of StarFFT section.



Begin of SingleFFT section.

Node(s) with error 0  
Node selected 1334  
Single FFT Gflop/s 0.435536  
Current time (1180080381) is Fri May 25 04:06:21 2007

End of SingleFFT section.

Begin of LatencyBandwidth section.

-----  
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart  
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany  
Details - level 2  
-----

MPI\_Wtime granularity.  
Max. MPI\_Wtick is 0.000001 sec  
wtick is set to 0.000001 sec

Message Length: 8  
Latency min / avg / max: 0.005186 / 0.005186 / 0.005186 msecs  
Bandwidth min / avg / max: 1.543 / 1.543 / 1.543 MByte/s

MPI\_Wtime granularity is ok.  
message size: 8  
max time : 10.000000 secs  
latency for msg: 0.005186 msecs  
estimation for ping pong: 0.466704 msecs  
max number of ping pong pairs = 21426  
max client pings = max server pongs = 146  
stride for latency = 17

Message Length: 8  
Latency min / avg / max: 0.000998 / 0.005393 / 0.006124 msecs  
Bandwidth min / avg / max: 1.306 / 1.516 / 8.013 MByte/s

Message Length: 2000000  
Latency min / avg / max: 10.182977 / 10.182977 / 10.182977 msecs  
Bandwidth min / avg / max: 196.406 / 196.406 / 196.406 MByte/s

MPI\_Wtime granularity is ok.  
message size: 2000000  
max time : 30.000000 secs  
latency for msg: 10.182977 msecs  
estimation for ping pong: 81.463814 msecs  
max number of ping pong pairs = 368  
max client pings = max server pongs = 19  
stride for latency = 109

Message Length: 2000000  
Latency min / avg / max: 10.131001 / 10.173062 / 10.206461 msecs  
Bandwidth min / avg / max: 195.954 / 196.598 / 197.414 MByte/s

Message Size: 8 Byte  
Natural Order Latency: 0.006104 msec  
Natural Order Bandwidth: 1.310720 MB/s  
Avg Random Order Latency: 0.017735 msec  
Avg Random Order Bandwidth: 0.451096 MB/s

Message Size: 2000000 Byte  
Natural Order Latency: 21.539450 msec  
Natural Order Bandwidth: 92.852883 MB/s  
Avg Random Order Latency: 94.330747 msec

Avg Random Order Bandwidth: 21.201995 MB/s

```
Execution time (wall clock)      = 72.957 sec on 2040 processes
- for cross ping_pong latency    = 7.494 sec
- for cross ping_pong bandwidth  = 28.893 sec
- for ring latency                = 0.985 sec
- for ring bandwidth              = 35.585 sec
```

```
-----
Latency-Bandwidth-Benchmark R1.5.1 (c) HLRS, University of Stuttgart
Written by Rolf Rabenseifner, Gerrit Schulz, and Michael Speck, Germany
Major Benchmark results:
```

```
-----
Max Ping Pong Latency:           0.006124 msecs
Randomly Ordered Ring Latency:   0.017735 msecs
Min Ping Pong Bandwidth:         195.954309 MB/s
Naturally Ordered Ring Bandwidth: 92.852883 MB/s
Randomly Ordered Ring Bandwidth: 21.201995 MB/s
-----
```

Detailed benchmark results:

Ping Pong:

```
Latency min / avg / max: 0.000998 / 0.005393 / 0.006124 msecs
Bandwidth min / avg / max: 195.954 / 196.598 / 197.414 MByte/s
```

Ring:

```
On naturally ordered ring: latency= 0.006104 msec, bandwidth= 92.852883 MB/s
On randomly ordered ring: latency= 0.017735 msec, bandwidth= 21.201995 MB/s
-----
```

Benchmark conditions:

```
The latency measurements were done with 8 bytes
The bandwidth measurements were done with 2000000 bytes
The ring communication was done in both directions on 2040 processes
The Ping Pong measurements were done on
- 14400 pairs of processes for latency benchmarking, and
- 361 pairs of processes for bandwidth benchmarking,
out of 2040*(2040-1) = 4159560 possible combinations on 2040 processes.
(1 MB/s = 10**6 byte/sec)
-----
```

Current time (1180080454) is Fri May 25 04:07:34 2007

End of LatencyBandwidth section.

Begin of Summary section.

```
VersionMajor=1
VersionMinor=0
VersionMicro=0
VersionRelease=b
LANG=C
Success=1
sizeof_char=1
sizeof_short=2
sizeof_int=4
sizeof_long=8
sizeof_void_ptr=8
sizeof_size_t=8
sizeof_float=4
sizeof_double=8
sizeof_s64Int=8
sizeof_u64Int=8
CommWorldProcs=2040
MPI_Wtick=9.536743e-07
HPL_Tflops=13.5322
```

HPL\_time=10641.3  
HPL\_eps=1.11022e-16  
HPL\_RnormI=9.99117e-08  
HPL\_AnormI=150490  
HPL\_AnormI=150357  
HPL\_XnormI=897682  
HPL\_XnormI=8.8349  
HPL\_N=600000  
HPL\_NB=200  
HPL\_nprow=30  
HPL\_npcol=68  
HPL\_depth=0  
HPL\_nbdiv=2  
HPL\_nbmin=4  
HPL\_cpfact=L  
HPL\_crfact=R  
HPL\_ctop=3  
HPL\_order=R  
HPL\_dMACH\_EPS=1.110223e-16  
HPL\_dMACH\_SFMIN=2.225074e-308  
HPL\_dMACH\_BASE=2.000000e+00  
HPL\_dMACH\_PREC=2.220446e-16  
HPL\_dMACH\_MLEN=5.300000e+01  
HPL\_dMACH\_RND=1.000000e+00  
HPL\_dMACH\_EMIN=-1.021000e+03  
HPL\_dMACH\_RMIN=2.225074e-308  
HPL\_dMACH\_EMAX=1.024000e+03  
HPL\_dMACH\_RMAX=1.797693e+308  
HPL\_sMACH\_EPS=5.960464e-08  
HPL\_sMACH\_SFMIN=1.175494e-38  
HPL\_sMACH\_BASE=2.000000e+00  
HPL\_sMACH\_PREC=1.192093e-07  
HPL\_sMACH\_MLEN=2.400000e+01  
HPL\_sMACH\_RND=1.000000e+00  
HPL\_sMACH\_EMIN=-1.250000e+02  
HPL\_sMACH\_RMIN=1.175494e-38  
HPL\_sMACH\_EMAX=1.280000e+02  
HPL\_sMACH\_RMAX=3.402823e+38  
dweeps=1.110223e-16  
sweps=5.960464e-08  
HPLMaxProcs=2040  
HPLMinProcs=2040  
DGEMM\_N=6642  
StarDGEMM\_Gflops=8.26893  
SingleDGEMM\_Gflops=8.49402  
PTRANS\_GBs=40.7648  
PTRANS\_time=17.6623  
PTRANS\_residual=0  
PTRANS\_n=300000  
PTRANS\_nb=100  
PTRANS\_nprow=30  
PTRANS\_npcol=68  
MPIRandomAccess\_N=274877906944  
MPIRandomAccess\_time=61.4053  
MPIRandomAccess\_CheckTime=33.6765  
MPIRandomAccess\_Errors=0  
MPIRandomAccess\_ErrorsFraction=0  
MPIRandomAccess\_ExeUpdates=15331277280  
MPIRandomAccess\_GUPs=0.249673  
MPIRandomAccess\_TimeBound=2660.33  
RandomAccess\_N=134217728  
StarRandomAccess\_GUPs=0.00253592  
SingleRandomAccess\_GUPs=0.00351655  
STREAM\_VectorSize=58823529  
STREAM\_Threads=1  
StarSTREAM\_Copy=1.03997  
StarSTREAM\_Scale=1.0575

```
StarSTREAM_Add=1.17648
StarSTREAM_Triad=1.21004
SingleSTREAM_Copy=2.95984
SingleSTREAM_Scale=3.05098
SingleSTREAM_Add=3.31801
SingleSTREAM_Triad=3.31212
FFT_N=33554432
StarFFT_Gflops=0.399146
SingleFFT_Gflops=0.435536
MPIFFT_N=17179869184
MPIFFT_Gflops=67.3302
MPIFFT_maxErr=2.22045e-15
MaxPingPongLatency_usec=6.12438
RandomlyOrderedRingLatency_usec=17.7346
MinPingPongBandwidth_GBytes=0.195954
NaturallyOrderedRingBandwidth_GBytes=0.0928529
RandomlyOrderedRingBandwidth_GBytes=0.021202
MinPingPongLatency_usec=0.998378
AvgPingPongLatency_usec=5.39269
MaxPingPongBandwidth_GBytes=0.197414
AvgPingPongBandwidth_GBytes=0.196598
NaturallyOrderedRingLatency_usec=6.10352
FFTEblk=16
FFTEnp=8
FFTEl2size=1048576
M_OPENMP=-1
omp_get_num_threads=0
omp_get_max_threads=0
omp_get_num_procs=0
MemProc=-1
MemSpec=-1
MemVal=-1
MPIFFT_time0=3.09944e-06
MPIFFT_time1=9.02557
MPIFFT_time2=3.8635
MPIFFT_time3=8.04679
MPIFFT_time4=12.7379
MPIFFT_time5=9.16573
MPIFFT_time6=4.05312e-06
End of Summary section.

#####
End of HPC Challenge tests.
Current time (1180080454) is Fri May 25 04:07:34 2007
#####
```

## 6.c. Comparison of application benchmarks

### 6.c.1. WRF

# Processors	# Nodes	# Cores	Time				Linear Scaling				Scaling Efficiency			
			NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large
1	1	1												
1	1	2												
2	1	4												
4	2	8												
8	4	16		8379				1				1		
16	8	32		4372				4189.5				0.95826		
32	16	64		2345	33863			2094.75	1			0.89328	1	
64	32	128		1253	18102			1047.38	16931.5			0.83589	0.93534	
96	48	192			12114				11287.7				0.93179	
128	64	256		737	10006			523.688	8465.75			0.71057	0.84607	
160	80	320												
192	96	384		599				349.125				0.58285		
224	112	448												
256	128	512		546	5666			261.844	4232.88			0.47957	0.74707	
384	192	768												
448	224	896												
512	256	1024												
1024	512	2048												
1536	768	3072												
2048	1024	4096												

Table 10.

### 6.c.2. OOCORE1

Expanded data not available.

## 6.c.3. GAMESS1

<b>standard.inp</b>												
MPI ver.												
#-way	#-nodes	Total wall time (s)			CPU utilization	Real time				Startup		
			Scalability	Efficiency		(min +	sec)	(s)	(s)	%	Scalability	Efficiency
16	4	14508	1	100.00%	99.17%	242	17.192	14537.19	29.192	0.20%	1	100.00%
32	8	7917	1.832512	91.63%	97.54%	132	33.846	7953.846	36.846	0.46%	1.828	91.38%
48	12	5707	2.542141	84.74%	96.29%	96	15.588	5775.588	68.588	1.19%	2.517	83.90%
64	16	4626	3.136187	78.40%	94.57%	78	11.126	4691.126	65.126	1.39%	3.099	77.47%
96	24	3582	4.050251	67.50%	91.36%	61	46.772	3706.772	124.772	3.37%	3.922	65.36%
128	32	3090	4.695146	58.69%	87.81%	52	51.608	3171.608	81.608	2.57%	4.584	57.29%
192	48	2843	5.10306	42.53%	83.62%	49	43.659	2983.659	140.659	4.71%	4.872	40.60%
256	64	2837	5.113853	31.96%	76.66%	49	5.8	2945.8	108.8	3.69%	4.935	30.84%
socket ver.												
#-way	#-nodes	Total wall time (s)			CPU utilization	Real time				Startup		
			Scalability	Efficiency		(min +	sec)	(s)	(s)	%	Scalability	Efficiency
16	4	14398	1	100.00%	0.9674	240	8.068	14408.07	10.068	0.07%	1	100.00%
32	8	7967	1.807	90.36%	0.9322	133	3.157	7983.157	16.157	0.20%	1.805	90.24%
48	12	5820	2.474	82.46%	0.9108	97	10.373	5830.373	10.373	0.18%	2.471	82.37%
64	16	4774	3.016	75.40%	0.8944	80	0.201	4800.201	26.201	0.55%	3.002	75.04%
96	24	3762	3.827	63.79%	0.8441	63	19.452	3799.452	37.452	0.99%	3.792	63.20%
128	32	3321	4.335	54.19%	0.801	56	13.991	3373.991	52.991	1.57%	4.270	53.38%
192	48	3087	4.664	38.87%	0.7426	52	40.465	3160.465	73.465	2.32%	4.559	37.99%
256	64	3123	4.610	28.81%	0.6816	53	44.793	3224.793	101.793	3.16%	4.468	27.92%
<b>large.inp</b>												
MPI ver.												
#-way	#-nodes	Total wall time (s)			CPU utilization	Real time				Startup		
			Scalability	Efficiency		(min +	sec)	(s)	(s)	%	Scalability	Efficiency
128	32	23459	1	100.00%	92.77%	392	21.645	23541.65	82.645	0.35%	1	100.00%
192	48	15757	1.489	99.25%	91.39%	264	30.689	15870.69	113.689	0.72%	1.483	98.89%
256	64	12103	1.938	96.91%	90.34%	203	45.447	12225.45	122.447	1.00%	1.926	96.28%
320	80	9976	2.352	94.06%	88.38%	169	2.116	10142.12	166.116	1.64%	2.321	92.85%
384	96	8593	2.730	91.00%	88.00%	148	43.477	8923.477	330.477	3.70%	2.638	87.94%
448	112	7545	3.109	88.83%	86.09%	130	22.32	7822.32	277.32	3.55%	3.010	85.99%
512	128	6869	3.415	85.38%	84.85%	117	18.43	7038.43	169.43	2.41%	3.345	83.62%
768	192	5283	4.440	74.01%	77.67%	95	41.957	5741.957	458.957	7.99%	4.100	68.33%
896	224	4923	4.765	68.07%	73.29%	90	18.02	5418.02	495.02	9.14%	4.345	62.07%
1024	256	4641	5.055	63.18%	70.80%	89	13.444	5353.444	712.444	13.31%	4.397	54.97%
socket ver.												

#-way	#-nodes	Total wall time (s)			CPU utilization	Real time			Startup			
			Scalability	Efficiency		(min +	sec)	(s)	(s)	%	Scalability	Efficiency
128	32	23971	1	100.00%	0.9022	400	13.418	24013.42	42.418	0.18%	1	100.00%
192	48	16208	1.478961	98.60%	0.8536	271	6.213	16266.21	58.213	0.36%	1.476276	98.42%
256	64	12287	1.950924	97.55%	0.8503	205	59.374	12359.37	72.374	0.59%	1.942932	97.15%
320	80	10030	2.38993	95.60%	0.8239	167	27.305	10047.31	17.305	0.17%	2.390036	95.60%
384	96	8640	2.774421	92.48%	0.8083	146	1.655	8761.655	121.655	1.39%	2.74074	91.36%
448	112	7645	3.135513	89.59%	0.8046	129	27.663	7767.663	122.663	1.58%	3.09146	88.33%

Table 11. (Compiler flags: "-O3 -q64 -qintsize=8 -qspillsize=1500 -qtbtable=full -qarch=ppc970 -qtune=ppc970 -lessl")

6.c.4. MILC2

# Processors	# Nodes	# Cores	Time				Perfect Scaling				Scaling Efficiency			
			NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large
1	1	1	92.581											
1	1	2												
2	1	4												
4	2	8												
8	4	16		1683.432				1				1		
16	8	32		865.036				841.716				0.97304158		
32	16	64		447.845	11316.27			420.858	1			0.93974031	1	
64	32	128		235.026	5781.716			210.429	5658.135			0.89534349	0.97862555	
96	48	192												
128	64	256		122.015	2964.596			105.2145	2829.0675			0.86230791	0.95428433	
160	80	320												
192	96	384												
224	112	448												
256	128	512			1537.605									
384	192	768												
448	224	896												
512	256	1024			817									
1024	512	2048			452	6554								1
1536	768	3072				3695								1.18249887
2048	1024	4096												

Table 12.

6.c.5. *PARATEC2*

# Processors	# Nodes	# Cores	Time				Linear Scaling				Scaling Efficiency			
			NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large	NSF Small	NSF Medium	NSF Large	NSF X-Large
1	1	1												
1	1	2												
2	1	4												
4	2	8												
8	4	16												
16	8	32		1323				1				1		
32	16	64		737	3794			661.5	1			0.89755767	1	
64	32	128		518	2415			330.75	1897			0.63851351	0.78550725	
96	48	192												
128	64	256			2068				948.5				0.45865571	
160	80	320												
192	96	384												
224	112	448												
256	128	512												
384	192	768												
448	224	896												
512	256	1024												
1024	512	2048												
1536	768	3072												
2048	1024	4096												

**Table 13.**

6.c.6. *HOMME3*

Expanded data not available.



## 7. Acknowledgements

Indiana University's Big Red supercomputer was funded in part by the Indiana METACyt Initiative and is supported in part by a Shared University Research grant from IBM Inc. to Indiana University. The Indiana METACyt Initiative is supported by a grant from the Lilly Endowment, Inc. to Indiana University. Big Red is connected to the NSF-funded TeraGrid. IU's participation in the TeraGrid is funded by National Science Foundation grant numbers 0338618, 0504075, and 0451237. The IU Data Capacitor was funded by grant number CNS-0521433. IU's work with LEAD has been supported by NSF grants ATM 0331480 and EIA-0202048. CICC was supported by P20HG003894-01. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF) or the National Institutes of Health (NIH). The authors wish to thank the people involved in building CTSS software on Big Red: Eric Blau, Charles Bacon, JP Navarro (University of Chicago), and Jason Brechin (National Center for Supercomputer Applications). The MyCluster component of CTSS was built by Evan Turner (Texas Advanced Computing Center) and the SRB client was built by George Kremenek (San Diego Supercomputer Center). Thanks to David Hart and Nancy Wilkins-Diehr (SDSC) and Suresh Marru (IU) for providing information and statistics related to the TeraGrid, LEAD, and Science Gateways generally. We would like to thank the staffs of the Research Technologies Division of UIITS, the Pervasive Technology Institute at IU, and ZIH at Technische Universität Dresden, for their contributions and effort that made the implementation of Big Red and the Data Capacitor, their integration within the TeraGrid, and the performance analysis possible. The authors would particularly like to thank Ray Sheppard and Malinda Lingwall for writing and editing. Gratitude goes particularly to IU President Michael A. McRobbie, whose leadership made Big Red's acquisition and implementation possible.

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