Running LINPACK benchmarks on Linux on Power

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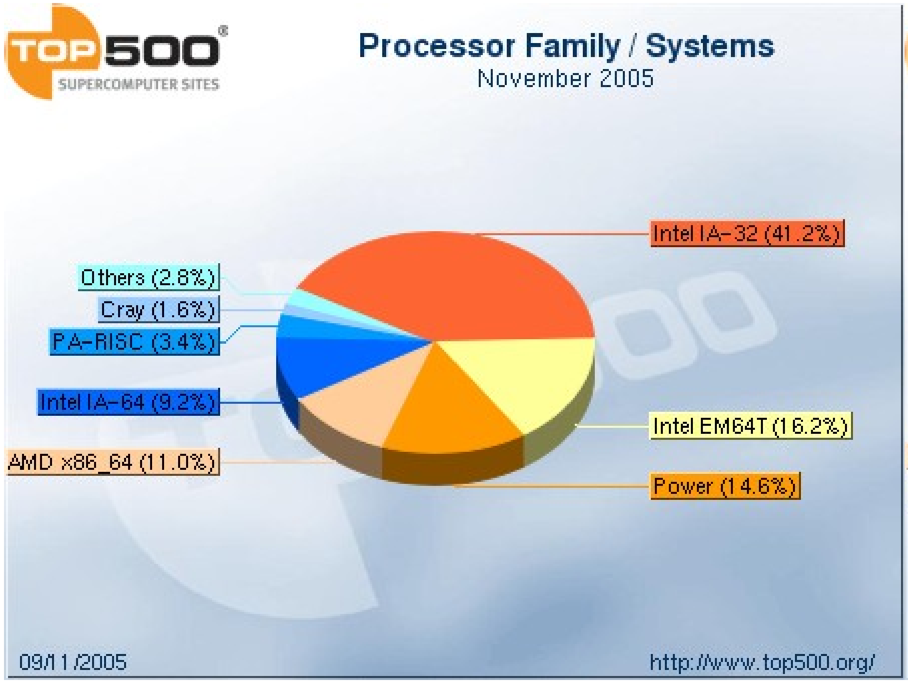
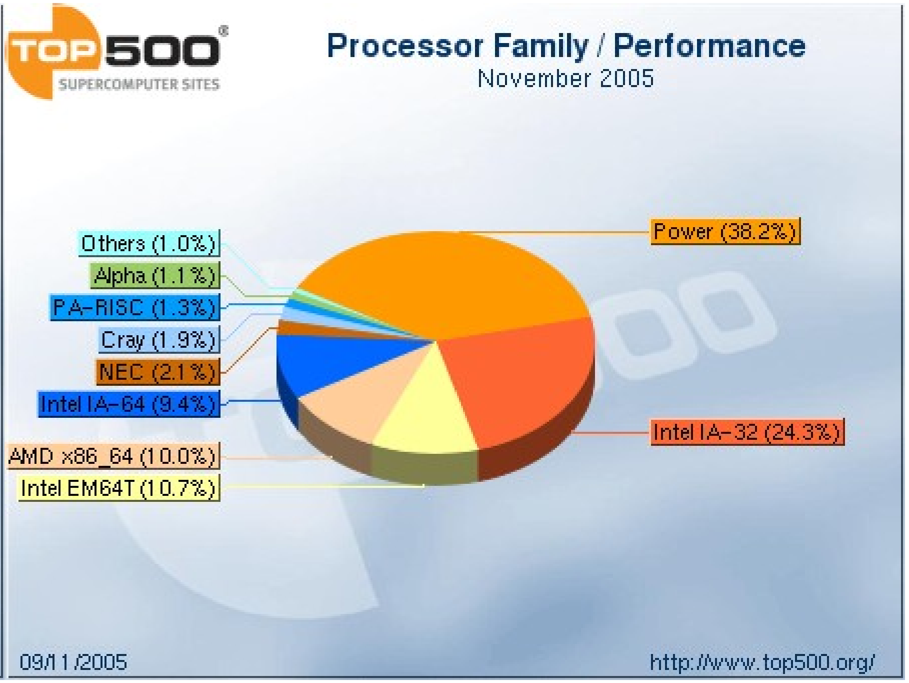
LINPACK and Top500

- Top 500 is a list of fastest computer systems in the world, updated twice a year
- LINPACK performance is used to do the ranking
- POWER is #1 performance architecture of Top500





Understanding Linpack HPC performance results

- System description

  IBM eServer BladeCenter JS20+ (2-way 2.2GHz PowerPC970 with Myrinet)

  IBM eSeries OpenPower 720 (2-way 1.6GHz POWER5 with Myrinet)

- R_{max}

  performance in Gflop/s for the largest problem run on the computer

- N_{max}

  Problem size used to achieve R_{max}

- $N_{1/2}$

  Problem size where half of the Rmax execution rate is achieved

- R_{peak}

  Theoretical peak performance in Gflop/s for the machine

LINPACK typical result output

```
============================================================================
T/V                N    NB     P     Q               Time             Gflops
----------------------------------------------------------------------------
W03R2L4       200000   152    32   150             344.69          1.547e+04
----------------------------------------------------------------------------
||Ax-b||_oo / ( eps * ||A||_1  * N        ) =        0.0121272 ...... PASSED
||Ax-b||_oo / ( eps * ||A||_1  * ||x||_1  ) =        0.0022087 ...... PASSED
||Ax-b||_oo / ( eps * ||A||_oo * ||x||_oo ) =        0.0004098 ...... PASSED
============================================================================
T/V                N    NB     P     Q               Time             Gflops
----------------------------------------------------------------------------
W03R2L4       977816   152    32   150           22331.19          2.791e+04
----------------------------------------------------------------------------
||Ax-b||_oo / ( eps * ||A||_1  * N        ) =        0.0014032 ...... PASSED
||Ax-b||_oo / ( eps * ||A||_1  * ||x||_1  ) =        0.0008878 ...... PASSED
||Ax-b||_oo / ( eps * ||A||_oo * ||x||_oo ) =        0.0001331 ...... PASSED
============================================================================
```

$$R_{max} = 27.91TF,\ R_{peak} = 42.24TF$$

What is needed to run LINPACK on POWER?

- LINPACK HPL
- BLAS (Basic Linear Algebra Subprogram) or VSIPL (Vector Signal Image Processing Library)
- MPI (Message Passing Interface) library
- IBM Linux on POWER compilers
- GNU/Linux distribution (RHEL, SLES)
- Large pages support

Source code

- HPL, version 1.0a
  http://www.netlib.org/benchmark/hpl
- BLAS (http://www.netlib.org/blas/):
  - IBM ESSL (binary-only)
  - Goto BLAS (binary-only)
    http://www.tacc.utexas.edu/~kgoto/
  - ATLAS
    http://math-atlas.sourceforge.net/
- Large pages support patch – more on this later

BLAS Libraries

- IBM ESSL and parallel ESSL
  http://www-03.ibm.com/systems/p/software/essl.html
- Implements very efficient DGEMM subroutine
- Allows for Myrinet-2000 communication using MPICH-GM for distributed DGEMM calls under Linux on POWER

BLAS Libraries (cont.)

- Goto BLAS
  http://www.tacc.utexas.edu/~kgoto/
  - Highly optimized BLAS implementation by Kazushige Goto of University of Texas, Austin
  - Available for POWER5 and PowerPC 970 (pSeries p5 systems, IBM BladeCenter JS20)
  - Available without charge to anyone for academic, research, experimental, or personal use
  - Contact Mr. Goto for special-kind versions – more on this later

Message Passing Interface

- MPI standard: http://www.mpi-forum.org/
- Some implementations for Linux on POWER:
  - MPICH – over Ethernet
  - MPICH-GM and MX – over Myrinet-2000
  - LAM/MPI and OpenMPI (Ethernet and Myrinet-2000)
  - IBM POE (experimental, in works)
- Good list of MPI implementations: http://www.lam-mpi.org/mpi/implementations/

Message Passing Interface (cont.)

- Pre-built MPI versions for Linux on POWER: http://ppclinux.ncsa.uiuc.edu/

- Simple self-contained LINPACK/MPI build environment will be available within IBM Redpaper “Running LINPACK benchmarks on 64-bit GNU/Linux” to be published December 2005
  http://www.redbooks.ibm.com

Large Pages

- A feature since 2.6 Linux kernel
- Documentation/vm/hugetlbpage.txt
- Linux on POWER supports 16Mb large pages
- Helps to minimize the size of page tables and TLB misses

- Substantially improves LINPACK performance on Linux on POWER, usually ~10% compared to 4Kb pages

Large pages setup

```
sysctl -w sys.vm.nr_hugepages=200
```

Before

```
$ cat /proc/meminfo
:
:
HugePages_Total:     0
HugePages_Free:      0
Hugepagesize:    16384 kB
:
:
```

After

```
$ cat /proc/meminfo
:
:
HugePages_Total:     200
HugePages_Free:      200
Hugepagesize:    16384 kB
:
:
```

Large pages (cont.)

- We aim for AIX-like setup:
  - No need to additional system configuration
  - Just link application with -blpdata

NOT IMPLEMENTED YET!!!

- Therefore:
  - Modify LINPACK to allocate on large pages
  - Modify BLAS library to use large pages
- Experimental Goto BLAS with large pages
- Experimental ESSL with large pages

Compiling and linking options

- For LINPACK HPL following options preffered when IBM compilers used on JS20:

```
CC        =mpicc -cc=xlc -q64
CCFLAGS   =$(HPL_DEFS) -O5 \
  -qtune=ppc970 -qarch=ppc970 -DUSE_LP
LINKER    =$(CC)
```

- For POWER5 change -qtune/-qarch to pwr5

LINPACK problem parameters

- Divide et impera:
  Proper system's division is a key to success

- How many MPI tasks?

- How many threads per each MPI task?

# MPI tasks x # Threads/task = # CPUs

LINPACK problem parameters (cont.)

- For example:

  8 2-way OpenPower P710 (8Gb RAM, Goto BLAS)

  8*2 = 16 CPUs (no SMT enabled)

  1 thread per task => 16 MPI tasks

  2 thread per task => 8 MPI tasks

- export GOTO_NUM_THREADS=1
- mpirun -np 16 -machinefile host.list ./xhpl

LINPACK problem parameters (cont.)

- Another key factor:
  process grid dimensions (PxQ)
- PxQ = # CPUs
- P : Q = 1 : 4 usually gives better performance
- Therefore, better to use perfect square #CPUs

$$P = \frac{\sqrt{number\ \ of\ \ CPUs}}{2}$$

LINPACK problem parameters (cont.)

- Problem size N depends on:
  - … total memory available
  - … number of large pages available
  - … number of MPI tasks
  - … interconnect library overhead
  - … system I/O buffering
- General formula:

memory size = N x N x 8 bytes

Problem size

- Common approaches:
  - The larger N, the better performance
  - Choose N as large as possible
  - N x N x 8 < total memory size
  - Keep swapping below zero

N x N x 8 = 16 x 8192 Mb => N = 131072

Problem size and large pages

- When large pages are used, the amount of memory available as large pages is used to estimate N.

- How many large pages to allocate on each system?

```
hpc2:~ # cat /proc/meminfo
MemTotal:      7864320 kB
MemFree:       7023508 kB
:
HugePages_Total:     0
HugePages_Free:      0
Hugepagesize:    16384 kB
```

```
Total free memory = 6858 MB
Allocate 428 LPs = 428 x 16MB = 6848 MB
```

Problem size and large pages (cont.)

- Reserve large pages for Goto BLAS or ESSL – usually 10-20 large pages per node
- Reserve some memory for system I/O buffers and network driver buffers – up to 10 large pages per node
- Reserve some memory for Myrinet-2000 infrastructure – up to 10 large pages
- Usual reserve is about 10% of large pages in total

N x N x 8 = # nodes x 428 x 0.9 x 16384 x 1024
N = 80390 (for 8 nodes)

System configuration

- /etc/sysctl.conf:

```
…
sys.vm.nr_hugepages=# Large Pages
sys.vm.disable_cap_mlock=1
kernel.shmmax=NxNx8
kernel.shmall=NxNx8
kernel.vm.swappiness=10
…
```

- sysctl -p

LINPACK problem parameters

- Block size: NB
- Empirically selected:

	Best NB
Goto for POWER5	256
Goto for JS20 Blade	256
Goto for large JS20 cluster	152
ESSL for POWER5	400
ESSL for JS20	200

LINPACK benchmark in brief

- Please read TUNING file in HPL source code distribution carefully
- Put appropriate N, P, Q, NB to HPL.dat
- Multiple combinations could be put, all to try in the same session
- Put xhpl, host.file, and HPL.dat on a shared disk
- Use mpirun to kick off the benchmark
- Collect results

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Thanks!

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