



TOP500 and Linpack

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LINPACK Benchmark

- Accidental benchmarking
 - Designed to help users extrapolate execution time for Linpack software
- First benchmark report from 1977

$\frac{2}{3} N^3$ ops
time

UNIT = 10**6 TIME / (1/3 100**3 + 100**2)

| Facility | TIME N=100 secs. | UNIT micro- secs. | Computer | Type | Compiler |
|-----------------|------------------------|-------------------------|----------------|------|--------------------|
| NCAR | 0.049 | 0.14 | CRAY-1 | S | CFT, Assembly BLAS |
| LASL | 0.148 | 0.43 | CDC 7600 | S | FTN, Assembly BLAS |
| NCAR | 0.192 | 0.56 | CRAY-1 | S | CFT |
| LASL | 0.210 | 0.61 | CDC 7600 | S | FTN |
| Argonne | 0.297 | 0.86 | IBM 370/195 | D | H |
| NCAR | 0.359 | 1.05 | CDC 7600 | S | Local |
| Argonne | 0.388 | 1.33 | IBM 3033 | D | H |
| NASA Langley | 0.489 | 1.42 | GDC Cyber 175 | S | FTN |
| U. Ill. Urbana | 0.506 | 1.47 | CDC Cyber 175 | S | Ext. 4.6 |
| LLL | 0.554 | 1.61 | CDC 7600 | S | CHAT, No optimize |
| SLAC | 0.579 | 1.69 | IBM 370/168 | D | H Ext., Fast mult. |
| Michigan | 0.631 | 1.84 | Amdahl 470/V6 | D | H |
| Toronto | 0.890 | 2.59 | IBM 370/165 | D | H Ext., Fast mult. |
| Northwestern | 1.44 | 4.20 | CDC 6600 | S | FTN |
| Texas | 1.93* | 5.63 | CDC 6600 | S | RUN |
| China Lake | 1.95* | 5.69 | Univac 1110 | S | V |
| Yale | 2.59 | 7.53 | DEC KL-20 | S | F20 |
| Bell Labs | 3.46 | 10.1 | Honeywell 6080 | S | Y |
| Wisconsin | 3.49 | 10.1 | Univac 1110 | S | V |
| Iowa State | 3.54 | 10.2 | Itel AS/5 mod3 | D | H |
| U. Ill. Chicago | 4.10 | 11.9 | IBM 370/158 | D | G1 |
| Purdue | 5.69 | 16.6 | CDC 6500 | S | FUN |
| U. C. San Diego | 13.1 | 38.2 | Burroughs 6700 | S | H |
| Yale | 17.1* | 49.9 | DEC KA-10 | S | F40 |

* TIME(100) = (100/75)**3 SGEFA(75) + (100/75)**2 SGESL(75)

Playstation 2 unoptimized.

My iPAQ running the benchmark in Java.

Linpack Benchmark report has 3 benchmarks.

Solve $Ax=b$, $n=100$, Fortran, no changes allowed, only compiler optimization

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Performance of Various Computers Using Standard Linear Equations Software

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An up-to-date version of this report can be found at <http://www.netlib.org/benchmark/performance.ps>
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Table 1: Performance in Solving a System of Linear Equations

| Computer | "LINPACK Benchmark" n = 100 | | "TPP" Best Effort n=1000, Mflop/s | "Theoretical Peak" Mflop/s |
|--|---|---------|---|-------------------------------|
| | OS/Compiler | Mflop/s | | |
| Intel Pentium 4 (2.8 GHz) | ifc -O3 -xW -ipo -ip -align | 1317 | 2444 | 5600 |
| Intel Pentium 4 (2.53 GHz) | ifc -O3 -xW -ipo -ip -align | 1190 | 2355 | 5060 |
| NEC SX-6/8 (8proc. 2.0 ns) | | | 41520 | 64000 |
| NEC SX-6/4 (4proc. 2.0 ns) | | | 23680 | 32000 |
| NEC SX-6/2 (2proc. 2.0 ns) | | | 13350 | 16000 |
| NEC SX-6/1 (1proc. 2.0 ns) | R12.1 -pi -WF ¹ -prob.use ² | 1161 | 7575 | 8000 |
| Fujitsu VPP5000/1(1 proc.3.33ns) | fvt -Wv,-r128 -Of -KA32 | 1156 | 8784 | 9600 |
| IBM eServer pSeries 655 651 4 proc(1300 MHz) | | | 10880 | 20800 |
| IBM eServer pSeries 655 651 1 proc(1300 MHz) | -O3 -qarch=pwr4 -qtune=pwr4 -Pv -Wp,-ea478,-g1 | 1135 | 2899 | 5200 |
| Cray T932 (32 proc. 2.2 ns) | | | 29360 | 57600 |
| Cray T928 (28 proc. 2.2 ns) | | | 28340 | 50400 |
| Cray T924 (24 proc. 2.2 ns) | | | 26170 | 43200 |
| Cray T916 (16 proc. 2.2 ns) | | | 19980 | 28800 |
| Cray T916 (8 proc. 2.2 ns) | | | 10880 | 14400 |
| Cray T94 (4 proc. 2.2 ns) | | | 5735 | 7200 |
| IBM eServer pSeries 650 6M2 8 proc(1450 MHz) | f90 -O3,inline2 | 1129 | 5735 | 7200 |
| IBM eServer pSeries 650 6M2 4 proc(1450 MHz) | | | 19930 | 46400 |
| IBM eServer pSeries 650 6M2 2 proc(1450 MHz) | | | 11190 | 23200 |
| IBM eServer pSeries 650 6M2 1 proc(1450 MHz) | -O3 -qarch=pwr4 -qtune=pwr4 -Pv -Wp,-ea478,-g1 | 1220 | 3245 | 5800 |
| hp rx5670 Itanium 2(4 proc 1GHz) | | | 11430 | 16000 |
| hp rx5670 Itanium 2(2 proc 1GHz) | | | 6284 | 8000 |
| hp rx5670 Itanium 2(1 proc 1GHz) | f90 +DSmckinley +O3 +Oinline.budget=100000 +Ono.ptrs.to.globals | 1102 | 3534 | 4000 |
| hp rx2600 Itanium 2(2 proc 1GHz) | | | 6251 | 8000 |
| hp rx2600 Itanium 2(1 proc 1GHz) | f90 +DSmckinley +O3 +Oinline.budget=100000 +Ono.ptrs.to.globals | 1102 | 3528 | 4000 |
| hp zx6000 Itanium 2(2 proc 1GHz) | | | 6315 | 8000 |
| hp zx6000 Itanium 2(1 proc 1GHz) | f90 +DSmckinley +O3 +Oinline.budget=100000 +Ono.ptrs.to.globals | 1102 | 3533 | 4000 |
| IBM eServer pSeries 690 Turbo 16 proc(1300 MHz) | | | 28080 | 83200 |
| IBM eServer pSeries 690 Turbo 8 proc(1300 MHz) | | | 18290 | 41600 |
| IBM eServer pSeries 690 Turbo 1 proc(1300 MHz) | -O3 -qarch=pwr4 -qtune=pwr4 -Pv -Wp,-ea478,-g1 | 1074 | 2894 | 5200 |

Table 3: Highly Parallel Computing

Third benchmark

- Ax=b
- Solve a large problem and measure the time.
- Have to get the "right" answer.

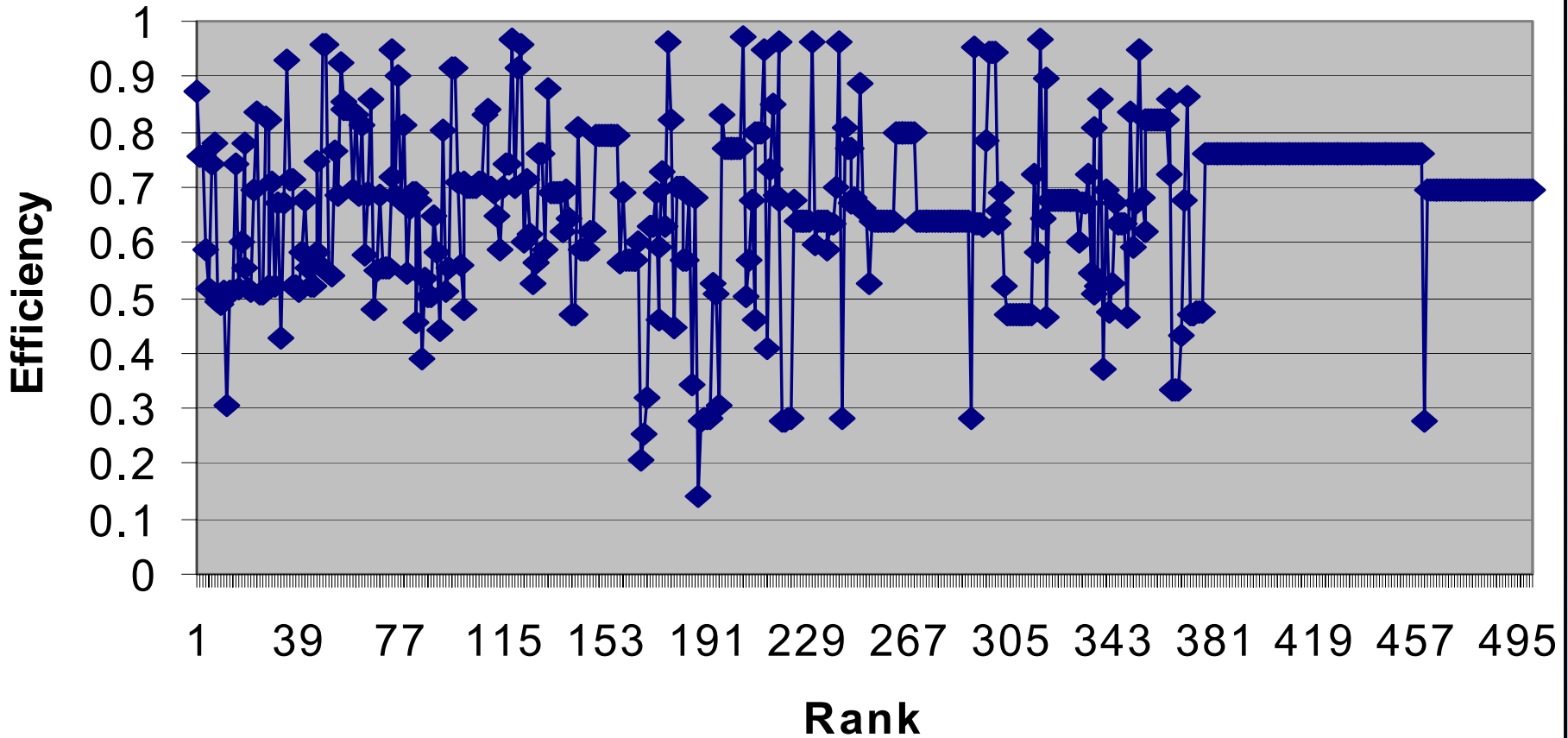
$$\frac{\|Ax - b\|}{\|A\| \cdot \|x\| \cdot n \cdot \varepsilon} = O(1)$$

- 64 bit arithmetic
- HPL software
- Use the matrix generator supplied.

| Computer (Full Precision) | Number of Processors | R_{max} Gflop/s | N_{max} order | $N_{1/2}$ order | R_{peak} Gflop/s |
|--|-------------------------|----------------------|--------------------|--------------------|-----------------------|
| Earth Simulator **** | 5120 | 35860 | 1075200 | 266240 | 40960 |
| ASCI Q AlphaServer EV-68 1.25 GHz | 4096 | 7727 | 590000 | 126100 | 10240 |
| ASCI Q AlphaServer EV-68 1.25 GHz | 4096 | 7679 | 576000 | 138600 | 10240 |
| ASCI White-Pacific, IBM SP Power 3(375 MHz) | 8000 | 7226 | 518096 | 179000 | 12000 |
| Compaq AlphaServer SC ES45/EV68 1GHz | 3016 | 4463 | 280000 | 85000 | 6032 |
| Compaq AlphaServer SC ES45/EV68 1GHz | 3024 | 4059 | 525000 | 105000 | 6048 |
| Linux NetworX/Quadrics(2.4 GHz Xeon w/Quad) | 1900 | 4049 | 350000 | 75000 | 9120 |
| Compaq AlphaServer SC ES45/EV68(1GHz w/Quad) | 2560 | 3980 | 360000 | 85000 | 5120 |
| HPTi Intel Xeon(2.2 Ghz,dual w/Myrinet) | 1536 | 3337 | 285000 | 75000 | 6758 |
| IBM p690 cluster, Power 4 1.3 GHz | 1200 | 3210 | 300000 | | 6240 |
| IBM SP Power3 208 nodes 375 MHz | 3328 | 3052. | 371712 | | 4992 |
| Compaq Alphaserver SC ES45/EV68(1GHz w/Quad) | 2048 | 2916 | 272000 | | 4096 |
| IBM eServer pSeries 690 Turbo(1.3 GHz POW4) | 1056 | 2713.0 | 240000 | | 5491 |
| IBM SP Power3 158 nodes 375 MHz | 2528 | 2526. | 371712 | 102400 | 3792 |
| ASCI Red Intel Pentium II Xeon core 333MHz | 9632 | 2379.6 | 362880 | 75400 | 3207 |
| IBM p690 cluster, Power 4 1.3 GHz | 864 | 2310 | 275000 | 62000 | 4493 |
| Atipa Tech. Pentium 4 (1.8 GHz w/Myrinet) | 1024 | 2207. | 280000 | 56000 | 3686 |
| ASCI Blue-Pacific SST, IBM SP 604E(332 MHz) | 5808 | 2144. | 431344 | 432344 | 3868 |
| ASCI Red Intel Pentium II Xeon core 333MHz | 9472 | 2121.3 | 251904 | 66000 | 3154 |
| Compaq Alphaserver SC ES45/EV68 1GHz | 1520 | 2096 | 390000 | 71000 | 3040 |
| Compaq Alphaserver SC ES45/EV68 1.25GHz | 1024 | 2037 | 320000 | | 2560 |
| PowerEdge HPC Cluster (2.4 GHz Xeon w/Gnet) | 600 | 2004. | 253400 | 42200 | 2880 |
| IBM p690 cluster, Power 4 1.3 GHz | 768 | 2002 | 252000 | | 3994 |
| IBM SP 112 nodes (375 MHz POWER3 High) | 1792 | 1791 | 275000 | 275000 | 2688 |
| HITACHI SR8000/MPP/1152(450MHz) | 1152 | 1709.1 | 141000 | 16000 | 2074 |
| IBM eServer pSeries 690 Turbo(1.3 GHz POW4) | 624 | 1696.0 | 221000 | | 3245 |
| HITACHI SR8000-F1/168(375MHz) | 168 | 1653. | 160000 | 19560 | 2016 |
| ASCI Red Intel Pentium II Xeon core 333Mhz | 6720 | 1633.3 | 306720 | 52500 | 2238 |
| SGI ASCI Blue Mountain | 5040 | 1608. | 374400 | 138000 | 2520 |
| IBM SP 328 nodes (375 MHz POWER3 Thin) | 1312 | 1417. | 374000 | 374000 | 1968 |
| IBM eServer pSeries 690 Turbo(1.3 GHz POW4) | 512 | 1384.0 | 200000 | | 2662 |
| Intel ASCI Option Red (200 MHz Pentium Pro) | 9152 | 1338. | 235000 | 63000 | 1830 |
| NEC SX-5/128M8(3.2ns) | 128 | 1192.0 | 129536 | 10240 | 1280 |
| CRAY T3E-1200 (600 MHz) | 1488 | 1127. | 148800 | 28272 | 1786 |
| IBM eServer pSeries 690 Turbo(1.3 GHz POW4) | 384 | 1038. | 245000 | | 1997 |
| HITACHI SR8000-F1/112(375MHz) | 112 | 1035.0 | 120000 | 15160 | 1344 |
| Intel ASCI Option Red (200 MHz Pentium Pro) | 7264 | 1068. | 215000 | 53400 | 1453 |
| Legend DeepComp 1800(2GHz Pent 4 w/Myrinet) | 512 | 1046 | 153600 | 49920 | 2048 |
| Linux NetworX/Quadrics(2.4 GHz Xeon w/Myri) | 391 | 1007 | 208000 | 25000 | 1732 |
| NEC SX-6/128M16 | 128 | 982.0 | 204800 | 12800 | 1024 |
| Linux NetworX/Quadrics(2.4 GHz Xeon w/Myri) | 352 | 962.8 | 200000 | 33000 | 1690 |
| Self-made Intel Pentium 2.2 GHz w/SCI3D | 400 | 960.4 | 220800 | 32800 | 1760 |
| SP Power3 375 MHz Nighthawk 2 | 1056 | 929.8 | 220000 | 62000 | 1584 |
| HITACHI SR8000-F1/100(375MHz) | 100 | 917.2 | 115000 | 15000 | 1200 |
| CRAY T3E-1200E (600 MHz) | 1080 | 891.5 | 259200 | 26400 | 1296 |

Linpack Efficiency; Average 67%

Linpack Efficiency



- Portable, runs on any system
- Easy to understand
- Content changed over time
 - $n=100, 300, 1000$, as large as possible (Top500)
 - Allows for restructuring algorithm
- Performance data with the same arithmetic precision
 - Benchmark checks to see if “correct solution” achieved
- Not intended to measure entire machine performance.
- In the benchmark report, “One further note: The following performance data should not be taken too seriously.”

- Historical data
- For $n=100$ same software for the last 25 years
- Unbiased reporting
- Freely available sw/results worldwide
- Should be able to achieve high performance on this problem, if not...
- Compiler test at $n=100$, heavily hand optimized at TPP (Modified ScaLAPACK implementation)
- Scalable benchmark, size and parallel
- Pressure on vendors to optimize (my) software and provide a set of numerical kernels that benefit others
- Run rules very important
- Today, $n = 1 \times 10^6$ at 35 TFlop/s requires ~6 hours
 - On a Petaflops machine, at $n=5 \times 10^6$ will require 1 day.