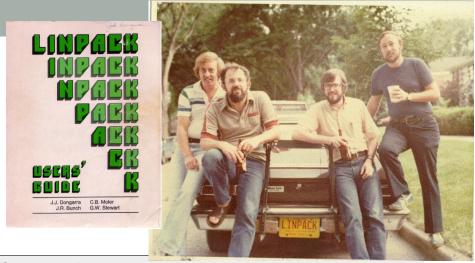
ACCIDENTAL BENCHMARKER

Jack Dongarra & Piotr Luszczek University of Tennessee/ORNL

Michael Heroux Sandia National Labs

Started 36 Years Ago

- In the late 70's the fastest computer ran LINPACK at 14 Mflop/s
- In the late 70's floating point operations were expensive compared to other operations and data movement
- Matrix size, n = 100
 - That's what would fit in memory

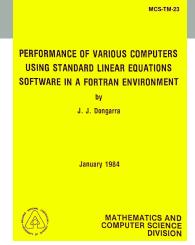


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- LINPACK code is based on "right-looking" algorithm:
 - O(n³) Flop/s and O(n³) data movement

LINPACK to HPL to TOP500 Changes over time

- LINPACK Benchmark report, ANL TM-23, 1984
 - Performance of Various Computers Using Standard Equations Software, listed about 70 systems.
- Over time the LINPACK Benchmark when through a number of changes.
 - Began with Fortran code, run the code as is, no changes, N = 100 (Table 1)
 - Later N = 1000 introduced, hand coding to allow for optimization and parallelism (Table 2)
 - Timing harness provided to generate matrix, check the solution
 - The basic algorithm, GE/PP, remained the same.
- 1989 started putting together Table 3 (Toward Peak Performance) of the LINPACK benchmark report.
 - N allowed to be any size
 - Timing harness provided to generate matrix, check the solution
 - List R_{max}, N_{max}, R_{peak}
- In 2000 we put together an optimized implementation of the benchmark, called High Performance LINPACK or HPL.
 - Sets the problem up and checks the results
 - Just needs optimized version of BLAS and MPI.



TOP500

- In 1986 Hans Meuer started a list of supercomputer around the world, they were ranked by peak performance.
- Hans approached me in 1992 to merge our lists into the "TOP500".
- The first TOP500 list was in June 1993.





Rank	Site	System	Cores	Rmax (GFlop/s)	Rpeak (GFlop/s)	Power (kW)
1	Los Alamos National Laboratory United States	CM-5/1024 Thinking Machines Corporation	1,024	59.7	131.0	
2	Minnesota Supercomputer Center United States	CM-5/544 Thinking Machines Corporation	544	30.4	69.6	
3	National Security Agency United States	CM-5/512 Thinking Machines Corporation	512	30.4	65.5	
4	NCSA United States	CM-5/512 Thinking Machines Corporation	512	30.4	65.5	
6	NEC Japan	SX-3/44R NEC	4	23.2	25.6	
6	Atmospheric Environment Service (AES)	SX-3/44	4	20.0	22.0	

High Performance LINPACK (HPL)

- Is a widely recognized and discussed metric for ranking high performance computing systems
- When HPL gained prominence as a performance metric in the early 1990s there was a strong correlation between its predictions of system rankings and the ranking that full-scale applications would realize.
- Computer vendors pursued designs that would increase their HPL performance, which would in turn improve overall application performance.
- Today HPL remains valuable as a measure of historical trends, and as a stress test, especially for leadership class systems that are pushing the boundaries of current technology.

LINPACK Benchmark – Still Learning Things

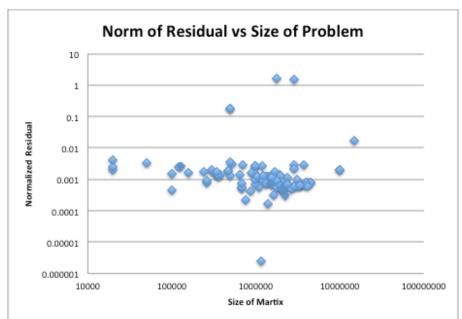
We use a backwards error residual to

check the "correctness" of the

solution.

 $\frac{\|b - Ax\|_{\infty}}{\varepsilon N \left(\|b\|_{\infty} + \|A\|_{\infty} \|x\|_{\infty}\right)}$

- This is the classical Wilkinson error bound.
 - If the residual is small O(1) then the software is doing the best it can independent of the conditioning of the matrix.
- We say O(1) is OK, the code allows the residual to be less than O(10).
- For large problems we noticed the residual was getting smaller.



LINPACK Benchmark – Still Learning Things

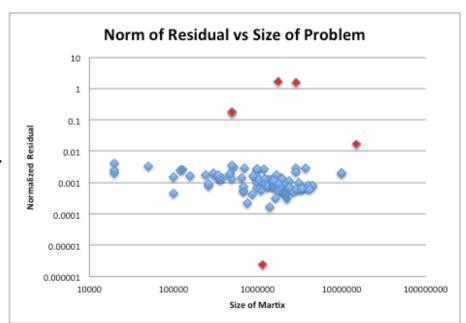
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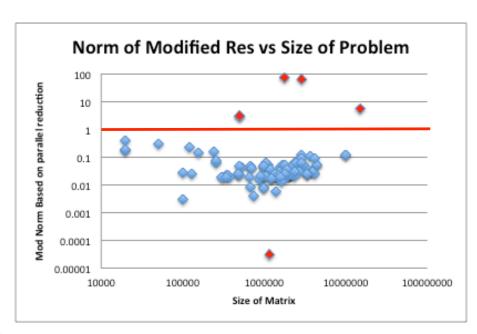
- This is the classical Wilkinson error bound.
 - If the residual is small O(1) then the software is doing the best it can independent of the conditioning of the matrix.
- We say O(1) is OK, the code allows the residual to be less than O(10).
- For large problems we noticed the residual was getting smaller O(10⁻³).
 - Allowing 4 decimal digits of potential error



LINPACK Benchmark - Still Learning Things

- The current criteria might be about O(10³) too lax which allows error for the last 10-12 bits of the mantissa to go undetected.
- We believe this has to do with the rounding errors for collective ops when done in parallel, i.e. MatVec and norms
- A better formulation of the residual might be:

$$\frac{\|b - Ax\|_{\infty}}{\varepsilon(N/Q)\log(Q)(\|b\|_{\infty} + \|A\|_{\infty}\|x\|_{\infty})}$$



Where $(N/Q)\log(Q)$

comes from the way the sums are done in Q chucks and then reduced in a log fashion.

Concerns

- HPL performance of computer systems are no longer so strongly correlated to real application performance, especially for the broad set of HPC applications governed by partial differential equations.
- The gap between HPL predictions and real application performance will increase in the future.
- A computer system with the potential to run HPL at an Exaflop is a design that may be very unattractive for real applications.
- Future architectures targeted toward good HPL performance will not be a good match for most applications.
- This leads us to a think about a different metric

HPL - Good Things

- Easy to run
- Easy to understand
- Easy to check results
- Stresses certain parts of the system
- Historical database of performance information
- Good community outreach tool
- "Understandable" to the outside world
- "If your computer doesn't perform well on the LINPACK Benchmark, you will probably be disappointed with the performance of your application on the computer."

HPL - Bad Things

- LINPACK Benchmark is 36 years old
 - TOP500 (HPL) is 20.5 years old
- Floating point-intensive performs O(n³) floating point operations and moves O(n²) data.
- No longer so strongly correlated to real apps.
- Reports Peak Flops (although hybrid systems see only 1/2 to 2/3 of Peak)
- Encourages poor choices in architectural features
- Overall usability of a system is not measured
- Used as a marketing tool
- Decisions on acquisition made on one number
- Benchmarking for days wastes a valuable resource

Running HPL

- In the beginning to run HPL on the number 1 system was under an hour.
- On Livermore's Sequoia IBM BG/Q the HPL run took about a day to run.
 - They ran a size of n=12.7 x 10⁶ (1.28 PB)
 - 16.3 PFlop/s requires about 23 hours to run!!

- The longest run was 60.5 hours
 - JAXA machine
 - Fujitsu FX1, Quadcore SPARC64 VII 2.52 GHz
 - A matrix of size n = 3.3 x 10⁶
 - .11 Pflop/s #160 today

#1 System on the TOP500 Over the Past 20 Years (16 machines in that club) 9 6 2

		r_max			
TOP500 List	<u>Computer</u>	(Tflop/s)	n_max	Hours	MW
6/93 (1)	TMC CM-5/1024	.060	52224	0.4	
11/93 (1)	Fujitsu Numerical Wind Tunnel	.124	31920	0.1	1.
6/94 (1)	Intel XP/S140	.143	55700	0.2	
11/94 - 11/95 (3)	Fujitsu Numerical Wind Tunnel	.170	42000	0.1	1.
6/96 (1)	Hitachi SR2201/1024	.220	138,240	2.2	
11/96 (1)	Hitachi CP-PACS/2048	.368	103,680	0.6	
6/97 - 6/00 (7)	Intel ASCI Red	2.38	362,880	3.7	.85
11/00 - 11/01 (3)	IBM ASCI White, SP Power3 375 MHz	7.23	518,096	3.6	
6/02 - 6/04 (5)	NEC Earth-Simulator	35.9	1,000,000	5.2	6.4
11/04 - 11/07 (7)	IBM BlueGene/L	478.	1,000,000	0.4	1.4
	IBM Roadrunner - PowerXCell 8i 3.2 Ghz	1,105.	2,329,599	2.1	2.3
11/09 - 6/10 (2)	Cray Jaguar - XT5-HE 2.6 GHz	1,759.	5,474,272	17.3	6.9
	NUDT Tianhe-1A, X5670 2.93Ghz NVIDIA	2,566.	3,600,000	3.4	4.0
6/11 - 11/11 (2)	Fujitsu K computer, SPARC64 VIIIfx	10,510.	11,870,208	29.5	9.9
	IBM Sequoia BlueGene/Q	16,324.	12,681,215	23.1	7.9
11/12 (1)	Cray XK7 Titan AMD + NVIDIA Kepler	17,590.	4,423,680	0.9	8.2
6/13 - 11/13 (2)	NUDT Tianhe-2 Intel IvyBridge & Xeon Phi	33,862.	9,960,000	5.4	17.8

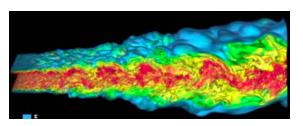
Many Other Benchmarks

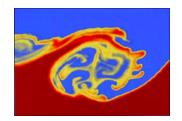
- TOP500
- Green 500
- Graph 500-160
- Sustained Petascale Performance
- HPC Challenge
- Perfect
- ParkBench
- SPEC-hpc
- Big Data Top100

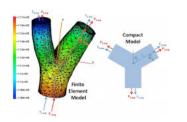
- Livermore Loops
- EuroBen
- NAS Parallel Benchmarks
- Genesis
- RAPS
- SHOC
- LAMMPS
- Dhrystone
- Whetstone
- I/O Benchmarks

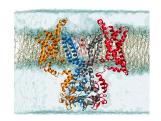
Goals for New Benchmark

 Augment the TOP500 listing with a benchmark that correlates with important scientific and technical apps not well represented by HPL









- Encourage vendors to focus on architecture features needed for high performance on those important scientific and technical apps.
 - Stress a balance of floating point and communication bandwidth and latency
 - Reward investment in high performance collective ops
 - Reward investment in high performance point-to-point messages of various sizes
 - Reward investment in local memory system performance
 - Reward investment in parallel runtimes that facilitate intra-node parallelism
- Provide an outreach/communication tool
 - Easy to understand
 - Easy to optimize
 - Easy to implement, run, and check results
- Provide a historical database of performance information
 - The new benchmark should have longevity

Proposal: HPCG

- High Performance Conjugate Gradient (HPCG).
- Solves Ax=b, A large, sparse, b known, x computed.
- An optimized implementation of PCG contains essential computational and communication patterns that are prevalent in a variety of methods for discretization and numerical solution of PDEs

Patterns:

- Dense and sparse computations.
- Dense and sparse collective.
- Data-driven parallelism (unstructured sparse triangular solves).
- Strong verification and validation properties (via spectral properties of CG).