NAS Parallel Benchmarks Results 3-95

Report NAS-95-011, April 1995

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Abstract

The NAS Parallel Benchmarks (NPB) were developed in 1991 at NASA Ames Research Center to study the performance of parallel supercomputers. The eight benchmark problems are specified in a "pencil and paper" fashion, i.e., the complete details of the problem are given in a NAS technical document. Except for a few restrictions, benchmark implementors are free to select the language constructs and implementation techniques best suited for a particular system. In this paper, we present new NPB performance results for the following systems:

(a) **Parallel-Vector Processors:** CRAY C90, CRAY T90, and Fujitsu VPP500;
(b) **Highly Parallel Processors:** CRAY T3D, IBM SP2-WN (Wide Nodes), and IBM SP2-TN2 (Thin Nodes 2);
(c) **Symmetric Multiprocessors**: Convex Exemplar SPP1000, CRAY J90, DEC Alpha Server 8400 5/300, and SGI Power Challenge XL (75 MHz).

We also present sustained performance per dollar for Class B LU, SP and BT benchmarks. We also mention future NAS plans for the NPB.

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1. Subhash Saini is an employee of Computer Sciences Corporation. This work was funded through NASA contract NAS 2-12961.

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1: Introduction

The Numerical Aerodynamic Simulation (NAS) Program, located at NASA Ames Research Center, is a pathfinder in high-performance computing for NASA and is dedicated to advancing the science of computational aerodynamics. One key goal of the NAS organization is to demonstrate by the year 2000 an operational computing system capable of simulating an entire aerospace vehicle system in one to several hours. It is currently projected that the solution of this Grand Challenge problem will require a system that can perform scientific computations at a sustained rate of approximately 1000 times faster than 1990 generation supercomputers. Such a computer system will most likely employ hundreds or even thousands of powerful RISC processors operating in parallel.

In order to objectively measure the performance of various highly parallel computer systems and to compare them with conventional supercomputers, NAS has developed the NAS Parallel Benchmarks (NPB) [1, 2]. Note that the NPB are distinct from the NAS High Speed Processor (HSP) benchmarks and procurements. The HSP benchmarks are used for evaluating production supercomputers for procurements in the NAS organization, whereas the NPB are used for studying highly parallel processor (HPP) systems in general.

2: NAS Parallel Benchmarks

The NPB consist of a set of eight benchmark problems, each of which focuses on some important aspect of highly parallel supercomputing for aerophysics applications. Some extension of Fortran or C is required for implementations, and reasonable limits are placed on the use of assembly code and the like. Otherwise, programmers are free to utilize language constructs that maximize performance on the particular system being studied. The choice of data structures, processor allocation, and memory usage are generally left open to the discretion of the implementer.

The eight problems consist of five kernels and three simulated computational fluid dynamics (CFD) applications. The five kernels comprise relatively compact problems, each emphasizing a particular type of numerical computation. Compared with the simulated CFD applications, they can be implemented fairly readily and provide insight as to the general levels of performance that can be expected on these specific types of numerical computations.

The simulated CFD applications, on the other hand, usually require more effort to implement, but they are more representative of the types of actual data movement and computation required in state-of-the-art CFD application codes. For example, in an isolated kernel, a certain data structure may be very efficient on a certain system; and yet, this data structure may be inappropriate if incorporated into a larger application. By comparison, the simulated CFD applications require data structures and implementation techniques that are more typical of real CFD applications.

(Space does not permit a complete description of these benchmark problems. A more detailed description of these benchmarks, together with the rules and restrictions associated with them, is given in Reference 2.)

Sample Fortran programs implementing the NPB on a single-processor system are available to aid implementers. These programs, as well as the benchmark document itself, are available by mail from: NAS Systems Division, Mail Stop 258-6, NASA Ames Research Center, Moffett Field, CA 94035, Attn: NAS Parallel Benchmark Codes. Or send an e-mail to:

`bm-codes@nas.nasa.gov`, or access the World Wide Web at URL:
`http://www.nas.nasa.gov/NAS/NPB/software/npb-software.html`

There are now two standard sizes for the NAS Parallel Benchmarks: Class A and Class B size problems. The nominal benchmark sizes for Class A and Class B problems are shown in Table 1. These tables also give the standard floating point operation (flop) counts. We recommend that those wishing to compute performance rates in millions of floating point operations per second (Mflop/s) use these standard flop counts. The tables contains Mflop/s rates calculated in this manner for the current fastest implementation on one processor of CRAY Y-MP for Class A and on one processor of CRAY C90 for Class B. Note, however, that in Tables 2 through 9, performance rates are *not* cited in Mflop/s; instead we present, the wall clock times (and, the equivalent performance ratios). We suggest that these, not Mflop/s, be examined when comparing different systems and implementations.

With the exception of the IS benchmark, these standard flop counts were determined by using the hardware performance monitor on the CRAY Y-MP or CRAY C90, and we believe that they are close to the minimal counts required for these problems. In the case of the IS benchmark, which does not involve floating-point operations, we selected a value approximately equal to the number of integer operations required, in order to permit the computation of performance rates analogous to Mflop/s rates. We reserve the right to change these standard flop counts in the future, if necessary.

The NAS organization reserves the right to verify any NPB results that are submitted to us. We may, for example, attempt to run the submitter's code on another system of the same configuration as that used by the submitter. In those instances where we are unable to reproduce the vendor's supplied results (allowing a 5% tolerance), our policy is to alert the submitter of the discrepancy and allow submitter to resolve the discrepancy in the next release of this report. If the discrepancy is not resolved to our satisfaction, then our own observed results and not the submitter's results will be reported. This policy will apply to all results NAS receives and publishes.

3: Benchmark Changes

Because the benchmarks are specified in only a "pencil and paper" fashion, it is inevitable that loopholes develop whereby the benchmark rules are not violated but the benchmark intent is defeated. Some changes have been made in Embarrassingly Parallel (EP) and Conjugate (CG) benchmark specifications in order to close some loopholes that have developed with these kernels [3].

4: NAS Parallel Benchmark Results

In the following section, each of the eight benchmarks will be briefly described, and then the best performance results we have received to date for each computer system will be given in Tables 2 through 9. These tables include run times and performance ratios. The performance ratios compare individual timings with the current best time for that benchmark achieved on one processor of CRAY Y-MP for Class A and on one processor of CRAY C90 for Class B. The run times in each case are elapsed time measured in accordance with the specifications of NPB rules. This paper reports benchmark results on the following systems: Convex Exemplar SPP1000 by CONVEX Computer Corporation; CRAY C90, CRAY J90, T3D, CRAY T90, CRAY Y-MP by Cray Research Inc. (CRI); DEC Alpha Server 8400 5/300 by Digital Equipment Corporation; IBM SP2-WN and IBM SP2-TN2 by International Business Machines (IBM); Fujitsu VPP500 by Fujitsu America Inc.; Power Challenge XL (75 MHz) by Silicon Graphics Inc.

This paper includes a number of new results including previously unpublished Convex Exemplar SPP1000, CRAY C90, CRAY J90, CRAY T3D, CRAY T90, DEC Alpha Server 8400 5/300, IBM SP2 and IBM SP-TN2 results. The benchmark results are presented under two classes: Kernels and CFD Applications.

Table 1: Standard operation counts for the NPB.

Benchmark Name	Abb.	Class A			Class B		
		Nominal Size	**Operation Count ($x\ 10^9$)**	**Mflop/s CRAY Y-MP/1**	**Nominal Size**	**Operation Count ($x10^9$)**	**Mflop/s CRAY C90/1**
Embarrassingly Parallel	EP	2^{28}	26.68	211	2^{30}	100.9	543
Multigrid	MG	256^3	3.905	176	256^3	18.81	498
Conjugate	CG	14×10^3	1.508	127	75×10^3	54.89	447
3-D FFT PDE	FT	$256^2 \times 128$	5.631	196	512×256^2	71.37	560
Integer Sort	IS	$2^{23} \times 2^{19}$	0.7812	68	$2^{25} \times 2^{21}$	3.150	244
LU Simulated CFD Application	LU	64^3	64.57	194	102^3	319.6	493
SP Simulated CFD Application	SP	64^3	102.0	216	102^3	447.1	627
BT Simulated CFD Application	BT	64^3	181.3	229	102^3	721.5	572

4.1: Kernels

The results for five kernels (EP, MG, CG, FT, and IS) are given below in the following section:

4.1.1: The Embarrassingly Parallel (EP) Benchmark

The first of the five kernel benchmarks is an *embarrassingly parallel* problem. In this benchmark, two-dimensional statistics are accumulated from a large number of Gaussian pseudo-random numbers, which are generated according to a particular scheme that is well-suited for parallel computation. This problem is typical of many *Monte Carlo* applications. Since it requires almost no communication, in some sense this benchmark provides an estimate of the upper achievable limits for floating point performance on a particular system. Results for EP benchmark are given in Table 2.

4.1.2: Multigrid (MG) Benchmark

The second kernel benchmark is a simplified multigrid kernel, which solves a 3-D Poisson PDE. This problem is simplified in the sense that it has constant rather than variable coefficients as in a more realistic application. This code is a good test of both short and long distance highly structured communication. The Class B problem uses the same size grid as of Class A but a greater number of inner loop iterations. Results for this benchmark are shown in Table 3.

4.1.3: Conjugate Gradient (CG) Benchmark

In this benchmark, a conjugate gradient method is used to compute an approximation to the smallest eigenvalue of a large, sparse, symmetric positive definite matrix. This kernel is typical of unstructured grid computations in that it tests irregular long-distance communication and employs sparse matrix vector multiplication. Results are shown in Table 4.

4.1.4: 3-D FFT PDE (FT) Benchmark

In this benchmark a 3-D partial differential equation is solved using FFTs. This kernel performs the essence of many *spectral methods*. It is a good test of long-distance communication performance. The rules of the NPB specify that assembly-coded, library routines may be used to perform matrix multiplication and one-dimensional, two-dimensional, or three-dimensional FFTs. Thus this benchmark is somewhat unique in that computational library routines may be legally employed. Results are shown in Table 5.

4.1.5: Integer Sort (IS) Benchmark

This benchmark tests a sorting operation that is important in *particle method* codes. This type of application is similar to particle-in-cell applications of physics, wherein particles are assigned to cells and may drift out. The sorting operation is used to reassign particles to the appropriate cells. This benchmark tests both integer computation speed and communication performance. This problem is unique in that floating point arithmetic is not involved. Significant data communication, however, is required. Results are shown in Table 6.

4.2: Simulated CFD Application Benchmarks

The three simulated CFD application benchmarks are intended to accurately represent the principal computational and data movement requirements of modern CFD applications.

4.2.1: LU Simulated CFD Application (LU) Benchmark

The first of these is the so-called the lower-upper diagonal (LU) benchmark. It does not perform a LU factorization but instead employs a symmetric successive over-relaxation (SSOR) numerical scheme to solve a regular-sparse, block *5x5* lower and upper triangular system. This problem represents the computations associated with a newer class of implicit CFD algorithms, typified at NASA Ames by the code *INS3D-LU*. This problem exhibits a somewhat limited amount of parallelism compared to the next two benchmarks. A complete solution of the LU benchmark requires 250 iterations. Results are given in Table 7.

4.2.2: SP Simulated CFD Application (SP) Benchmark

The second simulated CFD application is called the scalar pentadiagonal (SP) benchmark. In this benchmark, multiple independent systems of nondiagonally dominant, scalar pentadiagonal equations are solved. A complete solution of the SP benchmark requires 400 iteration. Results are given in Table 8.

4.2.3: BT Simulated CFD Application (BT) Benchmark

The third simulated CFD application is called the block tridiagonal (BT) benchmark. In this benchmark, multiple independent systems of non-diagonally dominant, block tridiagonal equations with a *5x5* block size are solved.

SP and BT are representative of computations associated with the implicit operators of CFD codes such as *ARC3D* at NASA Ames. SP and BT are similar in many respects, but there is a fundamental difference with respect to the communication to computation ratio. Timings are cited as complete run times, in seconds, as with the other benchmarks. For the BT benchmark, 200 iterations are required. Results of BT benchmark are given in Table 9.

5: Sustained Performance Per Dollar

One aspect of the relative performance of these systems has not been addressed so far, namely the differences in price between these systems. One should not be too surprised that the CRAY C90 system, for example, exhibits superior performance rates on these benchmarks, since its current list price is much greater than that of the other systems tested.

One way to compensate for these price differences is to compute sustained performance per million dollars, *i.e.* the performance ratio figures shown in Tables 2 through 9 divided by the list price in millions. Some figures of this type are shown in Tables 10-12 for Class B LU, SP, and BT benchmarks, respectively. The table includes the list price of the minimal system (in terms of memory per node and number of processors) required to run the full Class B size NPB as implemented by the vendor. These prices were provided by the vendors and include any associated software costs, i.e. operating system, compilers, scientific libraries as required, *etc.* but do not include maintenance. Note that some vendors' standard configurations may include substantially more hardware than required for the benchmarks, *e.g*., the IBM SP2). Finally, be aware that list prices are similar to the peak performance in that they are guaranteed not to be exceeded.

6: Observations and Comments

1. The Parallel-Vector Processor CRAY C90 is no longer the performance leader. The absolute performance of three CFD applications benchmarks LU, SP, and BT on 512 PEs of CRAY T3D and 160 nodes of IBM SP2-WN is significantly greater than on the 16 CPUs of Cray C90.

2. When the system performance is normalized by system price, all the highly parallel systems outperform the CRAY C90.

3. Portability of the NPB is a big issue. Each vendor uses its own programming paradigm for parallelization [4], for example:

   a. Convex SPP 1000: Convex specific directives for achieving parallelization.

   b. CRAY C90: Cray-specific directives (Microtasking and Autotasking).

   c. CRAY J90: Cray-specific directives.

   d. CRAY T3D: Explicit shared-memory model using `shmem_get` and `shmem_put`. This paradigm is not a message-passing paradigm.

   e. Fujitsu VPP500: Fujitsu-specific parallel directives.

   f. IBM SP2-WN and IBM SP2-TN2: IBM-specific message-passing library called MPL.

   g. SGI PC-XL (75 MHz) **:** SGI-specific directives.

4. To date no vendor has implemented NPB in Message Passing Interface (MPI) or High Performance Fortran (HPF). We recommend that vendors use either HPF or MPI for running NPB on their machines.

5. NAS is writing NPB in HPF and MPI. We hope to announce these at Supercomputing '95 in San Diego.

6. NAS is also upgrading existing NPB to include unstructured grids and multidisciplinary fields (coupling of fluids dynamics, structural mechanics, *etc.*) which will be announced/released at Supercomputing '96.

7. The best computer based on performance per dollar for Class B SP and BT benchmarks is a Symmetric Multiprocessor (SMP) machine called DEC Alpha Server 8400 5/300 (also called TurboLaser) from Digital Equipment Corporation. The peak performance of a single processor used in this SMP is 600 Mflop/s.

Table 2: Results of the Embarrassingly Parallel (EP) benchmark.

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Computer System	Date Received	No. Proc.	Class A		Class B	
			Time in Seconds	Ratio to CRAY Y-MP/1	Time in Seconds	Ratio to CRAY C90/1
Convex Exemplar SPP1000	Mar 95	1	376.8	0.33	NA	NA
		8	48.1	2.62	191.0	0.77
		16	24.3	5.19	96.0	1.53
		32	11.8	10.69	48.0	3.05
		64	6.1	20.68	24.5	5.98
CRAY C90	Feb 95	1	36.62	3.45	146.41	1.0
		2	18.42	6.85	73.66	1.99
		4	9.15	13.79	36.78	3.98
		8	4.61	27.37	18.37	7.97
		16	2.36	53.46	9.35	15.66
CRAY J90	Feb 95	1	169.44	0.74	NA	NA
		2	86.70	1.46	NA	NA
		4	43.09	2.93	NA	NA
		8	21.54	5.86	NA	NA
CRAY T3D	Feb 95	16	22.74	5.55	91.83	1.59
		32	11.37	11.10	45.92	3.19
		64	5.68	22.21	22.95	6.38
		128	2.87	43.96	11.47	12.76
		256	1.44	87.62	5.74	25.51
		512	0.72	175.24	2.87	51.01
		1024	0.55	229.40	2.19	66.85
CRAY T90	Feb 95	1	18.56	6.80	NA	NA
CRAY Y-MP	Aug 92	1	126.17	1.0	NA	NA
		8	15.87	7.95	NA	NA
Fujitsu VPP500	Aug 94	1	44.25	2.85	176.64	0.83
		4	11.24	11.23	44.52	3.29
		8	5.67	22.26	22.36	6.5
		16	2.87	43.96	11.26	13.00
		32	1.46	86.42	5.68	25.78
		64	0.75	168.23	2.88	50.84
IBM SP2-WN (Wide Nodes)	Mar 95	8	19.91	6.34	79.75	1.84
		16	9.95	12.69	39.89	3.67
		32	4.98	25.34	19.9	7.36
		64	2.49	50.6/7	9.95	14.71
		128	1.25	100.94	4.99	29.34
IBM SP2-TN2 (Thin Nodes 2)	Mar 95	8	20.82	6.06	82.94	1.77
		16	10.42	12.11	41.47	3.53
		32	5.23	24.12	20.75	7.06
		64	2.62	48.16	10.37	14.12
		128	1.31	96.31	5.19	28.21
Silicon Graphics Power Challenge XL (75 MHz)	Oct 94	1	242.95	0.52	973.62	0.15
		4	61.44	2.05	245.74	0.60
		8	30.77	4.10	122.98	1.19
		16	15.48	8.15	61.79	2.37

Table 3: Results of the Multigrid (MG) benchmark.

Computer System	Date Received	No. Proc	Class A Time in Seconds	Class A Ratio to CRAY Y-MP/1	Class B Time in Seconds	Class B Ratio to CRAY C90/1
Convex Exemplar SPP1000	Mar 95	1	208.0	0.11	NA	NA
		8	29.9	0.74	150.4	0.22
		16	17.3	1.28	85.1	0.40
		32	11.0	2.02	52.7	0.64
		64	NA	NA	39.6	0.85
CRAY C90	Feb 95	1	7.27	3.06	33.78	1.00
		2	3.71	5.99	17.24	1.96
		4	1.92	11.58	8.89	3.80
		8	1.10	20.20	4.59	7.36
		16	0.71	31.30	3.43	9.85
CRAY J90	Feb 95	1	39.08	0.57	NA	NA
		2	20.52	1.09	NA	NA
		4	10.75	2.07	NA	NA
		8	6.14	3.62	NA	NA
CRAY T3D	Feb 95	16	13.78	1.61	66.58	0.51
		32	6.40	3.47	30.10	1.11
		64	2.61	8.51	12.56	2.69
		128	1.36	16.34	6.57	5.14
		256	0.74	30.03	3.37	10.02
		512	0.39	56.97	1.74	19.41
		1024	0.25	88.88	1.15	29.38
CRAY T90	Feb 95	1	4.57	4.86	NA	NA
CRAY Y-MP	Aug 92	1	22.22	1.00	NA	NA
		8	2.96	7.51	NA	NA
Fujitsu VPP500	Mar 95	4	1.44	15.43	6.81	4.96
		8	0.75	29.63	3.59	9.41
		16	0.42	52.90	2.01	16.81
		32	0.26	85.46	1.26	26.81
IBM SP2-WN (Wide Nodes)	Oct 94	8	6.04	3.68	27.92	1.21
		16	3.17	7.01	14.58	2.32
		32	1.69	13.15	7.72	4.38
		64	0.95	23.39	4.36	7.75
		128	0.53	41.92	2.46	13.73
IBM SP2-TN2 (Thin Nodes 2)	Feb 95	8	7.18	3.09	32.73	1.04
		16	3.74	5.94	17.13	1.97
		32	1.99	11.17	9.14	3.96
		64	1.12	19.84	5.20	6.50
		128	0.63	35.27	2.95	11.45

Table 4: Results of the Conjugate Gradient (CG) benchmark.

Computer System	Date Received	No. Proc.	Class A		Class B	
			Time in Seconds	Ratio to Cray Y-MP/1	Time in Seconds	Ratio to Cray C90/1
Convex Exemplar SPP1000	Mar 95	1	202.9	0.06	NA	NA
		8	22.2	0.54	NA	NA
		16	8.94	1.33	837.0	0.15
		32	4.30	2.77	485.4	0.25
		64	NA	NA	292.1	0.42
CRAY C90	Feb 95	1	3.43	3.48	122.90	1.00
		2	1.79	6.66	63.11	1.95
		4	0.95	12.55	33.25	3.70
		8	0.53	22.49	18.11	6.79
		16	0.34	35.06	10.61	11.58
CRAY J90	Feb 95	1	15.93	0.75	NA	NA
		2	8.42	1.42	NA	NA
		4	4.42	2.70	NA	NA
		8	2.61	4.57	NA	NA
CRAY T3D	Feb 95	16	14.37	0.83	570.11	0.22
		32	7.44	1.60	291.30	0.42
		64	3.93	3.03	158.81	0.77
		128	2.11	5.65	82.07	1.50
		256	1.21	9.85	47.15	2.61
		512	0.72	16.56	27.34	4.50
		1024	0.58	20.6	16.58	7.41
CRAY T90	Feb 95	1	1.955	6.10	NA	NA
CRAY Y-MP	Aug 92	1	11.92	1.00	NA	NA
		8	2.38	5.01	NA	NA
Fujitsu VPP500	Aug 94	1	5.68	2.10	NA	NA
		2	3.06	3.90	104.51	1.18
		4	1.72	6.93	55.40	2.22
		8	1.04	11.46	31.80	3.86
		15	NA	NA	20.85	5.89
		16	0.80	14.90	NA	NA
		30	NA	NA	15.21	8.08
IBM SP2-WN (Wide Nodes)	Mar 94	8	4.91	2.43	156.21	0.79
		16	3.09	3.86	88.4	1.39
		32	2.09	5.70	52.53	2.34
		64	1.6	7.45	33.79	3.64
		128	1.38	8.64	25.44	4.83
IBM SP2-TN2 (Thin Nodes 2)	Mar 95	8	5.60	2.13	234.46	0.52
		16	3.48	3.43	120.23	1.02
		32	2.34	5.09	67.16	1.83
		64	1.72	6.93	38.52	3.19
		128	1.48	8.05	28.50	4.31
Silicon Graphics Power Challenge XL (75 MHz)	Oct. 94	1	39.0	0.31	NA	NA
		2	16.9	0.71	NA	NA
		4	7.2	1.66	NA	NA
		8	4.5	2.65	NA	NA
		16	3.5	3.41	NA	NA

Table 5: Results of the 3-D FFT PDE (FT) benchmark.

Computer System	Date Received	No. Proc	Class A		Class B	
			Time in Second	Ratio to Cray YMP/1	Time in Seconds	Ratio to Cray C90/1
Convex Exemplar SPP1000	Mar 95	1	178.6	0.16	NA	NA
		8	25.5	1.13	375.4	0.29
		16	20.5	1.40	NA	NA
		32	13.9	2.07	NA	NA
CRAY C90	Feb 95	1	8.95	3.21	110.60	1.00
		2	4.53	6.35	55.75	1.98
		4	2.29	12.56	27.95	3.96
		8	1.29	22.30	14.12	7.83
		16	0.80	35.97	7.65	14.46
CRAY J90	Feb 95	1	42.84	0.67	NA	NA
		2	22.08	1.30	NA	NA
		4	11.21	2.57	NA	NA
		8	6.15	4.68	NA	NA
CRAY T3D	Feb 95	16	11.80	2.44	NA	NA
		32	5.90	4.87	NA	NA
		64	2.99	9.62	40.57	2.73
		128	1.52	18.93	20.68	5.35
		256	0.77	37.36	10.77	10.27
		512	0.51	56.41	6.44	17.17
		1024	0.32	89.91	3.76	29.41
CRAY Y-MP	Feb 95	1	28.77	1.0	NA	NA
		8	4.19	6.87	NA	NA
CRAY T90	Feb 95	1	5.23	5.50	NA	NA
Fujitsu VPP500	Aug 94	4	2.93	9.82	NA	NA
		8	1.45	19.84	NA	NA
		16	0.75	38.36	7.95	13.91
		32	0.40	71.93	4.07	27.17
		64	0.24	119.88	2.18	50.73
IBM SP2-WN (Wide Nodes)	Oct 94	8	13.31	2.16	NA	NA
		16	7.17	4.01	91.8	1.20
		32	3.96	7.27	47.23	2.34
		64	2.19	13.4	26.05	4.25
		128	1.23	23.39	14.52	7.62
IBM SP2-TN2 (Thin Nodes 2)	Mar 95	8	14.78	1.95	NA	NA
		16	8.09	3.56	101.03	1.09
		32	4.31	6.68	51.38	2.15
		64	2.39	12.04	28.02	3.95
		128	1.30	22.13	15.68	7.05
Silicon Graphics Power Challenge XL (75 MHz)	Oct 94	1	61.17	0.47	761.67	0.15
		2	35.53	0.81	414.52	0.27
		4	19.98	1.44	223.97	0.49
		8	12.57	2.29	130.15	0.85
		16	11.18	2.57	110.37	1.00

Table 6: Results of the Integer Sort (IS) benchmark.

Computer System	Date Received	Number Processor	Class A		Class B	
			Time in seconds	Ratio to Cray Y-MP/1	Time in seconds	Ratio to Cray C90/1
Convex Exemplar SPP1000	Mar 95	1	83.2	0.14	NA	NA
		8	10.1	1.13	43.5	
CRAY C90	Feb 95	1	3.33	3.44	12.92	1.0
		2	1.64	6.99	6.50	1.99
		4	0.85	13.48	3.30	3.92
		8	0.46	24.91	1.73	7.47
		16	0.27	42.44	0.98	13.18
CRAY J90	Feb 95	1	13.75	0.83	NA	NA
		2	7.02	1.63	NA	NA
		4	3.81	3.00	NA	NA
		8	2.21	5.19	NA	NA
CRAY T3D	Feb 95	16	7.07	1.62	NA	NA
		32	3.89	2.95	16.57	0.78
		64	2.09	5.48	8.74	1.48
		128	1.05	10.91	4.56	2.83
		256	0.55	20.84	2.36	5.47
		512	0.31	36.97	1.33	9.71
		1024	0.44	26.05	1.22	10.59
CRAY T90	Feb 95	1	2.06	5.56	NA	NA
CRAY Y-MP	Aug 92	1	11.46	1.00	NA	NA
		8	1.85	6.19	NA	NA
Fujitsu VPP500	Apr 94	1	2.189	5.24	NA	NA
		2	1.574	7.28	NA	NA
		4	1.098	10.44	3.70	3.49
		8	0.917	12.50	3.03	4.26
IBM SP2-WN (Wide Nodes)	Mar 95	8	4.93	2.32	19.75	0.65
		16	2.65	4.32	10.60	1.22
		32	1.54	7.44	5.92	2.18
		64	0.89	12.88	3.41	3.79
		128	0.59	19.42	1.98	6.53
IBM SP2-TN2 (Thin Nodes 2)	Feb 95	8	5.16	2.22	20.79	0.62
		16	2.89	3.97	11.46	1.13
		32	1.66	6.90	6.37	2.03
		64	0.91	12.59	3.58	3.61
		128	0.61	18.79	2.05	6.30

Table 7: Results of the LU CFD Application (LU)benchmark.

Computer System	Date Received	No. Proc.	Class A		Class B	
			Time in Seconds	Ratio to Cray YMP/1	Time in Seconds	Ratio to Cray C90/1
Convex Exemplar SPP1000	Mar 95	1	2668	0.13	NA	NA
		8	331	1.00	1492	0.30
		16	196	1.70	827	0.54
		32	126	2.65	465.9	0.96
CRAY C90	Feb 95	1	119.78	2.78	449.54	1.00
		2	62.29	5.35	231.98	1.94
		4	32.20	10.36	121.26	3.71
		8	17.15	19.45	63.03	7.13
		16	10.17	32.79	37.93	11.85
CRAY J90	Feb 95	1	495.22	0.67	NA	NA
		2	260.58	1.28	NA	NA
		4	138.99	2.40	NA	NA
		8	77.70	4.29	NA	NA
CRAY T3D	Feb 95	16	205.69	1.62	844.53	0.53
		32	106.89	3.12	451.18	1.00
		64	55.32	6.03	233.45	1.93
		128	28.71	11.62	120.53	3.73
		256	15.94	20.92	65.06	6.9
		512	9.02	36.97	36.39	12.35
		1024	7.09	47.4	20.77	21.64
CRAY T90	Feb 95	1	82.67	4.03	NA	NA
CRAY Y-MP	Aug 92	1	333.5	1.00	NA	NA
		8	49.5	6.74	NA	NA
Fujitsu VPP500	Aug 94	1	146.89	2.27	591.05	0.76
IBM SP2-WN (Wide Nodes)	Mar 95	8	112.5	2.96	429.8	1.05
		16	64.6	5.16	234.4	1.92
		32	36.5	9.14	129.7	3.47
		64	22.7	14.69	76.8	5.85
		128	15.2	21.94	47.8	9.41
IBM SP2-TN2 (Thin Nodes 2)	Mar 95	8	120.8	2.76	477.3	0.94
		16	70.9	4.70	255.4	1.76
		32	40.1	8.32	141.3	3.18
		64	24.5	13.61	82.9	5.42
		128	15.9	20.97	51.2	8.78
Silicon Graphics Power Challenge XL (75 MHz)	Oct 94	1	604.0	0.55	2617.9	0.17
		4	231.8	1.44	1010.5	0.44
		8	111.7	2.99	550.2	0.82
		16	65.3	5.11	308.1	1.46

Table 8: Results of the SP simulated CFD application (SP) benchmark.

Computer System	Date Received	No. Proc.	Class A		Class B	
			Time in seconds	Ratio to Cray YMP/1	Time in seconds	Ratio to Cray C90/1
Convex Exemplar SPP1000	Mar 95	1	2533	0.19	NA	NA
		8	345	1.37	1584	0.44
		16	228	2.07	1068	0.65
		32	144	3.27	697.4	0.99
		64	102	4.62	449.5	1.5
CRAY C90	Feb 95	1	174.50	2.70	689.60	1.00
		2	87.32	5.40	345.57	2.00
		4	44.75	10.54	175.85	3.92
		8	22.74	20.73	90.80	7.59
		16	12.82	36.78	52.22	13.21
CRAY J90	Feb 95	1	871.34	0.54	NA	NA
		2	445.25	1.06	NA	NA
		4	232.43	2.03	NA	NA
		8	128.711	3.66	NA	NA
CRAY T3D	Feb 95	16	202.11	2.33	818.07	0.84
		32	104.10	4.53	463.62	1.49
		64	53.26	8.85	233.52	2.95
		128	27.54	17.12	130.45	5.29
		256	14.71	32.05	74.89	9.21
		512	8.91	52.92	42.63	16.18
		1024	5.41	87.15	25.23	27.33
CRAY T90	Feb 95	1	114.78	4.11	NA	NA
CRAY Y-MP	Aug 92	1	471.5	1.01	NA	NA
		8	64.6	7.30	NA	NA
DEC Alpha Server 8400 5/300	Mar 95	1	749.61	0.63	3448.10	0.20
		4	199.17	2.37	904.45	0.76
		8	118.04	3.99	452.13	1.53
		12	102.75	4.59	364.54	1.89
Fujitsu VPP500	Mar 95	1	99.309	4.75	404.08	1.71
		2	61.588	7.66	241.23	2.86
		4	32.114	14.68	127.48	5.41
		6	NA	NA	83.710	8.24
		8	16.399	28.75	64.930	10.62
		16	8.5761	54.98	NA	NA
		17	NA	NA	30.474	22.63
		32	4.5355	103.96	NA	NA
		34	NA	NA	15.674	44.0
		51	NA	NA	10.654	64.73
		64	2.5483	185.0	NA	NA
IBM SP2-WN (Wide Nodes)	Mar 95	8	143.8	3.27	589.3	1.17
		16	83.2	5.67	300.6	2.29
		32	48.7	9.68	163.8	4.21
		64	30.1	15.66	91.7	7.52
		128	18.7	25.21	54.8	12.58
IBM SP2-TN2 (Thin Nodes 2)	Mar 95	8	161.1	2.93	640.9	1.08
		16	93.3	5.05	342.3	2.01
		32	53.6	8.80	184.4	3.74
		64	32.7	14.42	101.6	6.79
		128	20.6	22.89	59.9	11.51
Silicon Graphics Power Challenge XL (75 MHz)	Oct 94	1	858.3	0.55	3719.5	0.19
		4	225.8	2.09	947.6	0.73
		8	119.5	3.95	491.4	1.40
		16	67.2	7.02	313.1	2.20

Table 9: Results of the BT simulated CFD application (BT) benchmark.

Computer System	Date Received	Number Processor	Class A		Class B	
			Time in seconds	Ratio to Cray Y-MP/1	Time in seconds	Ratio to Cray C90/1
Convex Exemplar SPP1000	Mar 95	1	2825	0.28	NA	NA
		8	366	2.17	1675	0.61
		16	211	3.76	984	1.04
		32	125	6.34	559.8	1.82
		64	78	10.16	338.2	3.03
CRAY C90	Feb 95	1	276.80	2.86	1023.4	1.00
		2	139.44	5.68	519.46	1.97
		4	72.11	10.99	265.20	3.86
		8	36.99	21.42	138.16	7.41
		16	20.30	39.03	78.80	12.99
CRAY J90	Mar 95	1	1209.64	0.66	NA	NA
		2	624.05	1.27	NA	NA
		4	324.73	2.44	NA	NA
		8	178.06	4.45	NA	NA
CRAY T3D	Feb 95	16	230.41	3.44	918.04	1.11
		32	115.53	6.85	476.97	2.15
		64	59.01	13.43	252.86	4.04
		128	29.96	26.44	128.21	7.98
		256	15.89	49.87	68.38	15.0
		512	8.39	94.45	38.01	26.92
		1024	4.56	173.77	20.45	50.04
CRAY T90	Feb 95	1	193.19	4.10	NA	NA
CRAY Y-MP	Aug 92	1	792.4	1.00	NA	NA
		8	114.0	6.95	NA	NA
DEC Alpha Server 8400 5/300	Mar 95	1	1113.90	0.71	4076.50	0.25
		2	551.80	1.44	2525.00	0.41
		4	286.97	2.76	1278.60	0.80
		8	146.91	5.39	649.53	1.58
		12	103.47	7.66	458.21	2.23
Fujitsu VPP500	Mar 95	1	142.42	5.56	NA	NA
		2	75.17	10.54	NA	NA
		4	39.14	20.25	NA	NA
		8	19.82	39.98	NA	NA
		16	9.99	79.32	NA	NA
		17	NA	NA	37.26	27.47
		32	5.09	155.68	NA	NA
		34	NA	NA	18.82	54.38
		51	NA	NA	12.61	81.16
		64	2.66	297.90	NA	NA
IBM SP2-WN (Wide Nodes)	Mar 95	8	206.7	3.83	862.8	1.19
		16	112.9	7.02	440.6	2.32
		32	61.8	12.82	226.8	4.51
		64	34.7	22.84	119.1	8.59
		128	20.1	39.42	67.0	15.27
IBM SP2-TN2 (Thin Nodes 2)	Feb 95	8	216.6	3.66	889.8	1.15
		16	118.0	6.72	459.2	2.23
		32	64.9	12.21	237.2	4.31
		64	36.3	21.83	124.8	8.20
		128	20.8	38.10	69.6	14.70
Silicon Graphics Power Challenge XL (75 MHz)	Oct 94	1	1330.3	0.60	5698.7	0.18
		4	355.9	2.23	1450.0	0.71
		8	177.0	4.48	775.0	1.32
		16	91.8	8.63	426.0	2.40

Table 10: Approximate sustained performance per dollar for Class B LU benchmark.

Computer System	# Proc	Memory	Ratio to C90/1	List Price Million $	Performance per Million $	Date
Convex SPP1000	32	4 GB	0.96	1.25	0.77	Mar 95
CRAY C90	16	2 GB	11.85	30.50	0.39	Mar 95
CRAY T3D No front end	128	64 MB/PE	3.73	3.6	1.04	Mar 95
IBM SP2-WN	64	128 MB/PE	5.85	5.94	0.98	Mar 95
IBM SP2-TN2	64	64 MB/PE	5.42	4.30	1.26	Mar 95
SGI PC-XL (75 MHz)	16	2 GB (total)	1.46	1.02	1.43	Jun 94

Table 11: Approximate sustained performance per dollar for Class B SP benchmark.

Computer System	# Proc	Memory	Ratio to C90/1	List Price Million $	Performance per Million $	Date
Convex SPP1000	64	8 GB	1.5	2.50	0.60	Mar 95
CRAY C90	16	2 GB	13.21	30.50	0.43	Mar 95
CRAY T3D No front end	128	64 MB/PE	5.29	3.6	1.47	Mar 95
DEC Alpha Server 8400 5/300	8	256 MB/PE	1.53	0.42	3.64	Mar 95
Fujitsu VPP500	51	256 MB/PE	64.73	31.00	2.09	Mar 95
IBM SP2-WN	64	128 MB/PE	7.52	5.94	1.27	Mar 95
IBM SP2-TN2	64	64 MB/PE	6.79	4.30	1.58	Mar 95
SGI PC-XL (75 MHz)	16	2 GB (total)	2.20	1.02	2.15	Jun 94

Table 12: Approximate sustained performance per dollar for Class B BT benchmark.

Computer System	# Proc	Memory	Ratio to C90/1	List Price Million $	Performance per Million $	Date
Convex SPP1000	64	8 GB	3.03	2.50	1.21	Mar 95
CRAY C90	16	2 GB	12.99	30.50	0.43	Mar 95
CRAY T3D No front end	128	64 MB/PE	7.98	3.6	2.22	Mar 95
DEC Alpha Server 8400 5/300	8	256 MB/PE	1.58	0.42	3.76	Mar 95
Fujitsu VPP500	51	256 MB/PE	81.16	31.00	2.62	Mar 95
IBM SP2-WN	64	128 MB/PE	8.59	5.94	1.45	Mar 95
IBM SP2-TN2	64	64 MB/PE	8.20	4.30	1.91	Mar 95
SGI PC-XL (75 MHz)	16	2 GB (total)	2.40	1.02	2.35	Jun 94

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