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Performance of Various Computers Using Standard Linear Equations Software in a Fortran Environment

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Technical Memorandum No. 23

August 1, 1988

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Abstract - This note compares the performance of different computer systems while solving dense systems of linear equations using the LINPACK software in a Fortran environment. About 100 computers, ranging from a CRAY X-MP to the 68000 based systems such as the Apollo and SUN Workstations to IBM PC's, are compared.

The timing information presented here should in no way be used to judge the overall performance of a computer system. The results reflect only one problem area: solving dense systems of equations using the LINPACK [1] programs in a Fortran environment.

LINPACK programs can be characterized as having a high percentage of floating point arithmetic operations. The routines involved in this timing study, SGEFA and SGESL, use column oriented algorithms. That is, the programs usually reference array elements sequentially down a column, not across a row. Column orientation is important in increasing efficiency because of the way Fortran stores arrays. Most floating point operations in LINPACK take place in a set of subprograms, the Basic Linear Algebra Subprograms (BLAS) [2] that are called repeatedly throughout the calculation. The BLAS reference one-dimensional arrays, rather than two-dimensional arrays.

The following four tables report timing results using LINPACK to solve a system of linear equations of order 100. The execution speeds, particularly for vector computers, may not have reached their asymptotic rates. (See the appendix for a different comparison of large scientific computers in Fortran.) It should be noted for Tables 1-4, no changes were made to the LINPACK software with the exception of replacing the BLAS. In certain cases, as noted, the Fortran BLAS were replaced by assembly language versions, or on vector machines the ''unrolled loops'' were replaced by simple loops in Fortran. For the LINPACK routines, no attempt was made to use special hardware features on certain machines, or to exploit vector capabilities or multiple processors. (The compilers on some machines may, of course, generate optimized code that itself accesses special features.)

One further note: The information in the tables was compiled over a period of time. Subsequent systems software and hardware changes may alter the timings to some extent.

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† Work supported in part by the Applied Mathematical Sciences subprogram of the Office of Energy Research, U. S. Department of Energy under Contract W-31-109-Eng-38.

TABLE 1

Solving a System of Linear Equations

with LINPACK [a] in Full Precision [b] Using All Fortran

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
CRAY Y-MP/832 (1 proc. 6ns)	CFT77 2.1(Rolled BLAS)	.17	74	.00946
ETA10-E (1 proc. 10.5ns)	ETAV/FTN200(Rolled BLAS)	.20	62	.011
CRAY X-MP/4 (1 proc. 8.5ns)	CFT77 2.1(Rolled BLAS)	.21	59	.012
CRAY X-MP/14se	CFT77 2.0(Rolled BLAS)	.27	46	.015
NEC SX-2	FORTRAN 77/SX(Rolled BLAS)	.28	43	.016
NEC SX-1	FORTRAN 77/SX(Rolled BLAS)	.34	36	.019
Hitachi S-820/80	HAP V21.00(Rolled BLAS)	.34	36	.019
CRAY 2S (1 proc.)	CFT77 2.0(Rolled BLAS)	.35	36	.019
ETA10-Q (1 proc. 19 ns)	ETAV/FTN200(Rolled BLAS)	.36	34	.020
NEC SX-1E	FORTRAN 77/SX(Rolled BLAS)	.38	32	.021
ETA10-P (1 proc. 24ns)	ETAV/FTN200(Rolled BLAS)	.45	27	.025
CRAY-1S	CFT77 2.1(Rolled BLAS)	.46	27	.026
NAS AS/XL V60	VAST/VS 1.4.1 opt=3	.58	21	.033
Fujitsu VP-400	Fortran 77 V10L30(Rolled BLAS)	.61	20	.034
Amdahl 1400	77/VP V10L20(Rolled BLAS)	.64	19	.036
Amdahl 1200	77/VP V10L20(Rolled BLAS)	.65	19	.036
Fujitsu VP-200	Fortran 77(Rolled BLAS)	.70	18	.039
CDC Cyber 205 (2-pipe)	FTN(Rolled BLAS)	.70	17	.039
Amdahl 1100	77/VP V10L20(Rolled BLAS)	.72	17	.040
Hitachi S-810/20	FORT77/HAP(Rolled BLAS)	.74	17	.042
Hitachi S-810/10	HAP V21.00(Rolled BLAS)	.75	16	.042
IBM 3090/180S VF	VS Fortran 2.3.0(Rolled BLAS)	.78	16	.043
Fujitsu VP-100	Fortran 77(Rolled BLAS)	.78	16	.044
Amdahl 500	77/VP V10L20(Rolled BLAS)	.78	16	.044
Siemens H120F	Fortran 77(Rolled BLAS)	.83	15	.465
Fujitsu VP-50	Fortran 77(Rolled BLAS)	.90	14	.051
IBM 3090/180E VF	VS 2.1.1 opt=3(Rolled BLAS)	.97	13	.054
CRAY-1S	**CFT 1.12 1983 (Rolled BLAS)**	**1**	**12**	**.056**
IBM 3090/180 VF	VS Fortran V2(Rolled BLAS)	1.0	12	.057
CDC Cyber 990E	FTN V2 VL=HIGH	1.1	12	.059
Sperry 1100/90 ext w/ISP	UCS level 2	1.1	11	.061
NAS AS/XL 60	VS 1.4.1 opt=3	1.1	11	.062
Cydrome Cydra 5	Fortran 77 Rel 2.3.0	1.2	10	.066
Prime MXCL 5	Fortran 77 Rel 2.3.0	1.2	10	.066
CONVEX C-210 (1 proc)	Fortran 4.0(Rolled BLAS)	1.2	10	.069
IBM 3090/180S	VS Fortran 2.3.0(Rolled BLAS)	1.3	9.6	.713
IBM 3090/150E VF	VS 2.1.1 opt=3(Rolled BLAS)	1.4	8.8	.078
Alliant FX/80 (8 proc)	FX v4.0.21(RolledBLAS)	1.4	8.5	.0805
NAS AS/9160	VAST/VS 1.4.1 opt=3	1.5	8.3	.083
SCS-40	CFT 1.13(Rolled BLAS)	1.5	8.0	.086
IBM 3090/120E VF	VS 2.1.1 opt=3(Rolled BLAS)	1.6	7.5	.092
IBM 3090/180E	VS 2.1.1 opt=3	1.7	7.4	.093
CONVEX C-130	Fortran 4.0(Rolled BLAS)	1.7	7.3	.098
Siemens 7890F	Fortran 77 V10.3	1.7	7.2	.096
IBM 3090/180	VS opt=3	1.8	6.8	.102

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Fujitsu M-380	Fortran 77, opt=3	1.9	6.3	.109
Ardent Titan-1 (1 proc)	Fortran prerelease 0.948 iinline(Rolled BLAS)	2.0	6.1	.113
Multiflow TRACE 7/200	Fortran 1.4(Rolled BLAS)	2.0	6.0	.114
Alliant FX/80 (4 proc)	FX v4.0.21(RolledBLAS)	2.1	5.8	.119
Siemens 7890G	Fortran 77 V10.3 opt=4	2.1	5.9	.116
IBM 3090/150E	VS 2.1.1 opt=3	2.1	5.9	.117
FPS-264 (M64/60)	F02 APFTN64 OPT=4(Rolled BLAS)	2.1	5.9	.117
Alliant FX/40 (4 proc)	FX v4.0.21(RolledBLAS)	2.3	5.3	.129
Honeywell DPS90	ES F77V 1.0(Rolled BLAS)	2.5	5.0	.138
Siemens 7890D	Fortran 77 V10.3	2.4	5.0	.138
Alliant FX/4 (4 proc)	FX v4.0.21(RolledBLAS)	2.5	4.9	.139
CDC Cyber 875	FTN 5 opt=3	2.6	4.8	.143
CDC Cyber 176	FTN 5.1 opt=2	2.6	4.6	.148
Amdahl 5860 HSFPF	H enhanced opt=3	3.1	3.9	.176
Amdahl 5860 HSFPF	VS opt=3	3.2	3.8	.181
MIPS M/2000	f77	3.4	3.6	.191
CONVEX C-120	Fortran 4.0(Rolled BLAS)	3.4	3.6	.192
NAS 8093 w/HSA	VS 1.4.0 opt=3	3.5	3.5	.197
Alliant FX/80 (2 proc)	FX v4.0.21(RolledBLAS)	3.6	3.4	.202
Alliant FX/40 (2 proc)	FX v4.0.21(RolledBLAS)	3.7	3.4	.205
CDC 7600	FTN	3.8	3.3	.210
Gould NP1	Fortran (Rolled BLAS)	3.9	3.1	.218
IBM 3090/120E	VS 2.1.1 opt=3	3.9	3.1	.221
FPS-264/20 (M64/50)	F02 APFTN64 OPT=4(Rolled BLAS)	4.1	3.0	.229
CONVEX C-1/XP	Fortran 2.0(Rolled BLAS)	4.1	3.0	.229
CONVEX C-1/XL	Fortran 1.6(Rolled BLAS)	4.2	2.9	.235
CDC Cyber 760	FTN 5, opt=3	4.7	2.6	.260
CyberPlus	CPFTN 1.1-07	4.8	2.6	.267
IBM 370/195	H enhanced opt=3	4.9	2.5	.275
IBM 3081 K (1 proc.)	H enhanced opt=3	5.7	2.1	.321
CDC Cyber 175	FTN 5 opt=2	5.8	2.1	.322
CDC Cyber 180-860	NOS/VE OPT=HIGH	5.8	2.1	.324
MIPS M120-5	UMIPS v.3 3.0 f771.31 -O	5.9	2.1	.330
FPS-M64/30	APFTN464 OPT=4	5.9	2.1	.332
Culler PSC	CSD Fortran 3.21	6.0	2.0	.337
IBM 3081 K (1 proc.)	VS opt=3	6.2	2.0	.346
CDC 7600	Local	6.4	2.0	.359
Alliant FX/80 (1 proc)	FX v4.0.21(RolledBLAS)	6.7	1.8	.374
Sperry 1100/90	FTN opt=ZEO	6.7	1.8	.374
Alliant FX/40 (1 proc)	FX v4.0.21(RolledBLAS)	6.7	1.8	.376
CDC Cyber 175	FTN 5 opt=1	6.8	1.8	.381
IBM 3033	H enhanced opt=3	7.0	1.7	.390
Honeywell DPS 8/88	FR7X	7.0	1.7	.394
IBM 3033	VS opt=3	7.1	1.7	.396
FPS-164/364 (M64/40)	F02 APFTN64 OPT=4(Rolled BLAS)	7.2	1.7	.405
Alliant FX/4 (1 proc)	FX v4.0.21(RolledBLAS)	7.4	1.6	.417
Sperry 1100/90 ext	UFTN	7.3	1.7	.408
IBM 3081 D	VS opt=3	7.4	1.7	.415
Amdahl 470 V/8	H enhanced opt=3	7.7	1.6	.429
CDC Cyber 170-750	FTN 5.1, opt=3	7.8	1.6	.436
CDC Cyber 180-850	NOS/VE OPT=HIGH	7.8	1.6	.436

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Siemens 7570-P	For1 1.6A	7.9	1.5	.442
NAS 8093	VS 1.4.0 opt=3	8.0	1.5	.448
ELXSI 6420	Unix 5.3 f77 -Oskm	8.0	1.5	.451
Amdahl 470 V/8	VS opt=3	8.2	1.5	.458
MIPS M/1000	UMIPS 2.03 f77 1.30 -O	8.4	1.5	.470
IBM 4381-23	VS Fortran 2.1.1 opt=3	9.1	1.3	.510
MIPS M/800	f77 1.30	9.8	1.2	.560
CDC 7600	CHAT, No opt	9.9	1.2	.554
Prime P6350	f77 rev 20.2.b2 -opt	10	1.2	.568
Alliant FX/1	FX v4.0.21(RolledBLAS)	10	1.2	.572
IBM 4381-13	VS 1.4.0 opt=3	10	1.2	.579
IBM 370/168 Fast Mult	H Ext	10	1.2	.579
CSPI MAP-6430	Fortran 1.5.35	10	1.2	.586
ELXSI 6420	Fortran 5.14 opt=10	11	1.2	.591
SUN 4/260	f77 -O sys4-beta2	11	1.1	.640
Amdahl 470 V/6	H opt=2	11	1.1	.631
CDC Cyber 180-840	NOS/VE OPT=HIGH	12	.99	.694
DEC VAX 8550/8700/8800	VMS v4.5	12	.99	.695
IBM 4381-22	VS Fortran 2.1.1 opt=3	13	.97	.709
IBM 4381 MG2	VS Fortran opt=3	13	.96	.718
IBM 4381-12	VS Fortran 1.4.0 opt=3	13	.95	.726
ICL 3980 w/FPU	FORTRAN77 PLUS V10.02	13.2	.93	.737
Siemens 7860E	Fortran 77 V10.3	13	.92	.757
Concurrent 3280XP	Fortran VII,Z 8.1	14	.87	.787
MIPS M800 w/R2010 FP	f77 1.10	14	.87	.790
Gould PN 9005	VTX/32 2.0 Fortran 77	14	.87	.792
IBM 9370-90	VS Fortran 1.3.0 opt=3	16	.78	.880
IBM 370/165 Fast Mult	H Ext	16	.77	.890
Prime P9955II	f77 rev 20.2.b2 -opt	17	.72	.960
DEC VAX 8530	VMS v4.6	17	.73	.934
DEC VAX 8650	VMS v4.5	18	.70	.980
DEC VAX 8500	VMS v4.5	19	.65	1.05
Mentor Graphics Computer	fortran	20	.60	1.14
Sperry 1100/80 w/SAM	FTN opt=ZEO	21	.58	1.18
CDC Cyber 930-31	NOS/VE 1.2.2	21	.58	1.19
Harris H1200	VOS 4.1 opt g	22	.56	1.22
Harris HCX-9	hf77 -O3	25	.50	1.36
Pyramid 9810	OSx 4.0	24	.50	1.37
DEC VAX 8600	VMS v4.5	26	.48	1.43
Harris HCX-7 w/fpp	f77 1.0	26	.48	1.43
CDC 6600	FTN 4.6 opt=2	26	.48	1.44
CDC Cyber 170-835	FTN 5 opt=2	26	.47	1.45
CCI Power 6/32 w/fpa	UNIX 4.2 bsd f77	26	.47	1.45
IBM 4381-21	VS Fortran 2.1.1 opt=3	26	.47	1.47
Sperry 7000	4.2	26	.47	1.47
Gould PN9000	UNIX	26	.47	1.47
SUN-3/260 + FPA	3.2 f77 -O -ffpa	27	.46	1.48
IBM 4381 MG1	VS Fortran opt=3	27	.46	1.49
DEC VAX 6210 (1 proc.)	VMS v5.0	27	.46	1.50
CDC Cyber 170-835	FTN 5 opt=1	28	.44	1.57
HP 9000 Series 840	HP-UX 14.3	28	.43	1.59

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Apollo DN5xxT FPX	DOMAIN/IX SR9.7 opt 4	30	.40	1.68
Harris H1000	VOS 3.3 opt g	30	.41	1.67
micro VAX 3200/3500/3600	VMS v4.6	30	.41	1.67
IBM 9370-60	VS Fortran 1.4.0 opt=3	31	.40	1.72
SUN-3/160 + FPA	3.2 f77 -O -ffpa	31	.40	1.73
Prime P9755	f77 rev 20.2.b2 -opt	31	.40	1.74
Ridge 3200 Model 90	ROS/rf	31	.39	1.76
IBM 4381-11	VS Fortran 1.4.0 opt=3	31	.39	1.76
Gould 32/9705 mult acc	fort77+ 4.3	31	.39	1.76
NORSK DATA ND-570/2	Fortran-500-E	32	.38	1.80
Sperry 1100/80	FTN opt=ZEO	32	.38	1.80
CDC Cyber 930-11	NOS/VE OPT=High	33	.37	1.84
CSA w/T800C-20	Fortran 3L	34	.37	1.88
CONCEPT 32/8750	UTX/32	34	.36	1.88
Celerity C1230	UNIX 4.2 bsd f77	34	.36	1.90
IBM RT PC 6150/115 fpa2	f77	34	.36	1.90
CDC 6600	RUN	34	.36	1.93
Gould PN9080	UTX/32	35	.35	1.97
Prime 9950	F77 19.4.2	36	.34	2.00
Opus Series 300pm 30 MHz	UNIX Greenhills	37	.33	2.08
Masscomp MC5600 w/fpa	f77 v1.2 -O3 rtv v3.1	38	.33	2.10
Data General MV/10000	f77 opt level 2	40	.30	2.26
IBM 4361 MG5	VS Fortran opt=3	41	.30	2.31
IRIS 2400 Turbo/FPA	f77	50	.24	2.82
CDC Cyber 180-830	NOS/VE OPT=HIGH	52	.24	2.89
Harris 800	Fortran 77	53	.23	2.99
IBM 370/158	H opt=3	53	.23	2.99
Gould PN 6005	VTX/32 2.0 Fortran 77	54	.23	3.02
IBM 370/158	VS Fortran opt=3	56	.22	3.15
NORSK DATA ND-560	Fortran-500	57	.22	3.20
Celerity C1200	UNIX 4.2 bsd f77	58	.21	3.23
Honeywell DPS 8/70	FR7X	58	.21	3.24
Denelcor HEP	f77 UPX	59	.21	3.32
VAX 11/785 FPA	VMS v4.5	61	.20	3.43
CDC Cyber 170-720	FTN 5, opt=2	62	.20	3.47
Itel AS/5 mod 3	H	63	.19	3.54
NORSK DATA ND-500	Fortran-500-E	63	.19	3.54
Kontron KSM/386	UNIX SVS f77 2.8	64	.19	3.60
CDC Cyber 170-825	FTN 5, opt=2	65	.19	3.63
IBM 4341 MG10	VS Fortran opt=3	66	.19	3.70
Pyramid 98xe	OSx 4.0	67	.18	3.72
IBM 9370-40	VS Fortran 1.4.0 opt=3	67	.18	3.74
VAX 11/785 FPA	UNIX 4.2 bsd f77	67	.18	3.75
DEC VAX 8250/8350 (UP)	VMS v4.6	67	.18	3.75
CDC Cyber 170-825	FTN 5, opt=1	68	.18	3.81
Ridge Server/RT EFP	ROS/rf	68	.18	3.83
CDC Cyber 170-720	FTN 5, opt=1	70	.17	3.93
Ridge 32/130	ROS 3.3/RISC	71	.17	3.96
Concurrent 3252	OS 6.2.4 fortran z	71	.17	4.00
Tektronix 4315 w/68882	UTEK f77	73	.17	4.10
CDC Cyber 180-810	NOS/VE OPT=HIGH	74	.17	4.14

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Prime P2755	f77 rev 20.2.b2 -opt	74	.17	4.14
Concurrent 3242	OS 32 v7.2 f77	80	.16	4.50
DEC VAX 8200/8300	VMS v4.5	82	.15	4.58
ICL 2988	f77 OPT=2	85	.14	4.78
Apollo DN4000	DOMAIN/IX SR9.7 opt 4	87	.14	.490
VAX 11/780 FPA	VMS v4.5	88	.14	4.90
IBM 9370-20	VS Fortran 1.4.0 opt=3	89	.14	5.00
micro VAX II	VMS v4.5	94	.13	5.28
Prime P2450	f77 rev 20.2.b2 -opt	95	.13	5.31
VAX 11/750 FPA	VMS v4.1	99	.12	5.52
CONCEPT 32/6750	UTX/32	99	.12	5.53
CDC 6500	FUN	102	.12	5.69
IBM RT w/68881	f77	103	.12	5.79
Prime 750	Primos f77 v19.1	107	.11	6.00
ENCORE Multimax NS32332	f77	107	.11	6.01
SUN-3/260, 20 MHz 68881	3.2 f77 -O -f68881	108	.11	6.00
Tektronix 4315 w/68881	UTEK f77	108	.11	6.05
HP 9000 Series 350	HP-UX, f77 5.2	108	.11	6.06
Definicon DSI-780	SVS Fortran (MSDOS)	109	.11	6.09
Concurrent 3230	OS 6.2.2 fortran 5.2	112	.11	6.28
VAX 11/780 FPA	UNIX 4.3 BSD f77 -O	115	.11	6.42
SUN-3/160, 16.7 MHz 68881	3.2 f77 -O -f68881	121	.101	6.70
Apollo DN590	DOMAIN/IX SR9.7 opt 4	124	.099	6.93
Masscomp MC5600 68881	f77 v1.2 -O3 rtv v3.1	124	.099	6.93
VAX 11/750 FPA	UNIX 4.2 bsd f77	128	.096	7.15
Prime 850	Primos	130	.095	7.26
Sperry 1100/60	FTN opt=ZEO	132	.093	7.38
Pyramid 90X FPA	UNIX 4.2 bsd f77	137	.088	7.65
SUN-3/50, 16.7 MHz 68881	3.2 f77 -O -f68881	139	.087	7.70
HP 9000 Series 330	HP-UX, f77 5.2	141	.087	7.92
micro VAX II	f77 Ultrix 1.1	150	.082	8.41
Ridge 32/110	ROS 3.3/RISC	151	.081	8.48
Data General MV/8000	f77 opt level 2	157	.078	8.80
Apple Mac/Levco Prodigy 4	ABSOFT MacFort 020	160	.076	9.00
Prime P2350	f77 rev 20.2.b2 -opt	160	.077	8.95
HP 9000 Series 320	HP-UX, f77 5.2	168	.073	9.42
Apollo DN3000	DOMAIN/IX SR9.7 opt 4	173	.071	9.66
Apollo DN460/660	AEGIS 8.0 FTN	179	.069	10.0
Masscomp MC500 w/FPP	3.1 Fortran	200	.061	11.2
Harris HS-20 w/FPP	Fortran 77 3.1	202	.061	11.3
Sequent Balance 8000	DYNIX Fortran 2.4.4	208	.059	11.7
Definicon DSI-32/10	GreenHills f77 (MSDOS)	214	.057	12.0
VAX 11/750	VMS v4.1	215	.057	12.1
ENCORE Multimax	f77	221	.055	12.4
HP 9000 Series 500	Fortran 1.7	285	.043	16.0
Opus 32.32	UNIX, f77 4.2 bsd	285	.043	16.0
ATT 3B20 FP	UNIX V 2.0/4	310	.040	17.3
Acorn Cambridge	fortran	312	.039	17.5
IBM 4331 MG2	H opt=3	326	.038	18.3
Burroughs B6800	Fortran 77 ver 34	329	.037	18.4
VAX 11/725 FPA	VMS v4.1	330	.037	18.5

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Masscomp MCS-541 w/FPB	Fortran 3.1	332	.037	18.6
IBM RT PC Model 20	f77	341	.036	19.1
VAX 11/730 FPA	VMS	348	.036	19.5
Prime 2250	Fortran 77	365	.034	20.5
IBM PC-AT/370	VS Fortran opt=3	369	.033	20.7
IBM PC-XT/370	H opt=3	391	.031	21.9
VAX 11/750	UNIX 4.2 bsd f77	422	.029	23.7
Apollo DN320	AEGIS 8.0 FTN	440	.028	24.6
SUN-2/50 + SKY FFP	f77 -O -fsky 3.0	454	.027	25.4
Ametek S14/32 (1 node)	RM Fortran 2.11	464	.264	26.0
Apollo DN550 FPA	AEGIS 8.0 FTN	489	.025	27.4
micro VAX I	VMS	529	.023	29.6
Canaan	VS	588	.021	33.0
Chas. River Data 6835+SKY	SVS Fortran 77	700	.018	39.2
Apollo DN 420 PEB	AEGIS 7+ FTN	707	.017	39.6
IBM AT w/80287	PROFORT 1.0	1054	.012	59.1
IBM PC w/8087	PROFORT 1.0	1054	.012	59.1
Cadtrak DS1/8087	Intel Fortran 77	1143	.011	64.0
IBM PC/AT w/80287	Microsoft 3.2	1341	.0091	75.1
Chas. River Data 6835	SVS Fortran 77	1401	.0088	78.5
Apollo DN300	AEGIS 8.0 FTN	1719	.0071	96.4
Masscomp MC500	3.1 Fortran	1751	.0070	98.1
IBM PC w/8087	Microsoft 3.2	1766	.0069	98.9
HP 9000 Series 200	HP-UX	1982	.0062	111.
SUN-2/50	f77 -O -fsoft 3.0	2232	.0055	125.
SUN	UNIX, f77 no opt	2661	.0046	149.
Apple Macintosh	ABSOFT 2.0b	3196	.0038	179.

Table 2

Solving a System of Linear Equations

with LINPACK [a] in Full Precision [b] Using Coded BLAS

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
CRAY Y-MP/832 (1 proc. 6ns)	CFT77 2.1(Coded BLAS)	.14	87	.00793
CRAY X-MP/4 (1 proc. 8.5ns)	CFT77 2.1(Coded BLAS)	.18	69	.010
ETA10-E (1 proc. 10.5ns)	ETAV/FTN200(Coded BLAS)	.20	61	.011
CRAY X-MP/14se	CFT77 2.0(Coded BLAS)	.23	54	.013
NAS AS/XL V60	VS 1.4.1 opt=3(Coded BLAS)	.29	42	.016
CRAY 2S	CFT77 2.0(Coded BLAS)	.30	41	.017
Amdahl 1400	77/VP V10L20(Coded BLAS)	.40	31	.022
Amdahl 1200	77/VP V10L20(Coded BLAS)	.42	29	.023
CRAY-1S	CFT77 2.1(Coded BLAS)	.45	28	.025
ETA10-P (1 proc. 24ns)	ETAV/FTN200(Coded BLAS)	.46	27	.026
Amdahl 1100	77/VP V10L20(Coded BLAS)	.50	25	.028
CDC Cyber 205 (4-pipe)	FTN200 2.1.6(Coded BLAS)	.50	25	.028
CDC Cyber 205 (2-pipe)	FTN200 2.1.6(Coded BLAS)	.53	23	.029
CRAY-1S	*CFT 1.12 1983 (Coded BLAS)*	*.54*	*23*	*.030*
Amdahl 500	77/VP V10L20(Coded BLAS)	.55	22	.031
IBM 3090/180S VF	VS Fortran 2.3.0(Coded BLAS)	.63	19	.036
IBM 3090/180E VF	VS 2.1.1 opt=3(Coded BLAS)	.76	16	0.043
IBM 3090/180 VF	VS Fortran V2(Coded BLAS)	.83	15	.047
NAS AS/9160	VS 1.4.1 opt=3(Coded BLAS)	.90	14	.050
IBM 3090/150E VF	VS 2.1.1 opt=3(Coded BLAS)	1.0	12	.058
SCS-40/XM	CFT 1.13(Coded BLAS)	1.0	12	.0581
CyberPlus	CPFTN 1.1-07(Coded BLAS)	1.1	12	.059
Alliant FX/80 (8 proc)	FX v4.0.21(Coded BLAS)	1.1	10.9	.0631
IBM 3090/120E VF	VS 2.1.1 opt=3(Coded BLAS)	1.2	10.	.068
CONVEX C-210 (1 proc)	Fortran 4.0(Coded BLAS)	1.2	10	.069
SCS-40	CFT 1.13(Coded BLAS)	1.3	9.3	.074
FPS-264 (M64/60)	APFTN464(Coded BLAS)	1.4	9	.076
Alliant FX/40 (4 proc)	FX v4.0.21(Coded BLAS)	1.8	6.8	.101
Alliant FX/80 (4 proc)	FX v4.0.21(Coded BLAS)	1.7	7.4	.0935
CONVEX C-130	Fortran 4.0(Coded BLAS)	1.7	7.3	.098
Alliant FX/4 (4 proc)	FX v4.0.21(Coded BLAS)	1.9	6.6	.104
CDC Cyber 875	FTN 5 opt=3(Coded BLAS)	2.2	5.5	.124
FPS-264/20 (M64/50)	F02 APFTN64 OPT=4(Coded BLAS)	2.6	4.6	.148
CDC 7600	FTN(Coded BLAS)	2.6	4.6	.148
Alliant FX/80 (2 proc)	FX v4.0.21(Coded BLAS)	2.8	4.4	.156
Alliant FX/40 (2 proc)	FX v4.0.21(Coded BLAS)	2.8	4.4	.156
MIPS M/2000	f77(Coded BLAS)	3.1	4.0	.171
CDC Cyber 760	FTN 5, opt=3(Coded BLAS)	3.3	3.7	.186
CONVEX C-120	Fortran 4.0(Coded BLAS)	3.4	3.6	.192
CONVEX C-1/XP	Fortran 2.0(Coded BLAS)	3.7	3.3	.207
CONVEX C-1/XL	Fortran 1.6(Coded BLAS)	3.7	3.3	.209
FPS-164/364 (M64/40)	F.01 D, opt=3(Coded BLAS)	4.2	2.9	.232
SUN 3 w/SKY VORTEX/VPA	f77(Coded BLAS)	4.2	2.9	.236
FPS- (M64/60)	APFTN464(Coded BLAS)	4.4	2.8	.276
Alliant FX/80 (1 proc)	FX v4.0.21(Coded BLAS)	5.3	2.3	.295

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Alliant FX/40 (1 proc)	FX v4.0.21(Coded BLAS)	5.3	2.3	.295
MIPS M120-5	UMIPS v.3 3.0 f771.31 -O(Coded BLAS)	5.5	2.2	.310
Alliant FX/4 (1 proc)	FX v4.0.21(Coded BLAS)	5.9	2.1	.332
IBM 4381-23 M/A asst	VS 2.1.1 opt=3(Coded BLAS)	6.9	1.78	.386
ELXSI 6420	Fortran 5.14 opt=10(Coded BLAS)	7.3	1.7	.410
IBM 4381-13 M/A asst	VS 1.4.0 opt=3(Coded BLAS)	7.7	1.6	.430
MIPS M/1000	MIPS 2.03 f77 1.21 -O(Coded BLAS)	7.9	1.6	.440
CSPI MAP-6430	Fortran 1.5.35(Coded BLAS)	8.4	1.5	.469
Alliant FX/1	FX v4.0.21(Coded BLAS)	9	1.4	.505
Prime P6350	f77 21.0 -OPT(Coded BLAS)	9.2	1.3	.514
IBM 4381-22 M/A asst	VS 2.1.1 opt=3(Coded BLAS)	9.4	1.30	.529
IBM 4381-12 M/A asst	VS 1.4.0 opt=3(Coded BLAS)	9.6	1.3	.540
IBM 4381 MG2 M/A asst	VS opt=3(Coded BLAS)	10	1.2	.559
Mentor Graphics Computer	fortran	11	1.2	.597
DEC VAX 8550/8700/8800	VMS v4.6(Coded BLAS)	11	1.2	.594
MIPS M800 w/R2010 FP	f77 1.10(Coded BLAS)	11	1.1	.620
DEC VAX 8650	VMS v4.5(Coded BLAS)	13	.96	.715
Gould PN 9005	VTX/32 2.0 Fortran 77(Coded BLAS)	13	.94	.733
DEC VAX 8530	VMS v4.6(Coded BLAS)	14	.86	.798
Harris H1200	VOS 4.1 opt g(Coded BLAS)	14	.85	.805
Prime P9955II	f77 21.0 -OPT(Coded BLAS)	15	.81	.843
Gould PN9000	UNIX(Coded BLAS)	15	.81	.850
NORSK DATA ND-570/2	Fortran-500-E(Coded BLAS)	16	.76	.900
DEC VAX 8500	VMS v4.5(Coded BLAS)	16	.76	.903
Harris HCX-9	hf77 -O3(Coded BLAS)	18	.66	1.03
IBM 4381-21 M/A asst	VS 2.1.1 opt=3 (Coded BLAS)	19	.65	1.06
IBM 4381 MG1 M/A asst	VS opt=3(Coded BLAS)	19	.65	1.06
DEC VAX 8600	VMS v4.5(Coded BLAS)	19	.66	1.04
IBM 4381-11 M/A asst	VS 1.4.0 opt=3(Coded BLAS)	21	.59	1.16
Celerity C1230	UNIX 4.2 bsd f77(Coded BLAS)	21	.59	1.17
Harris H1000	VOS 3.3 opt g(Coded BLAS)	22	.57	1.21
DEC VAX 6210 (1 proc.)	VMS v5.0	22	.56	1.22
HP 9000 Series 840	HP-UX 14.3(Coded BLAS)	23	.54	1.27
Ridge 3200 Model 90	ROS/rf(Coded BLAS)	24	.50	1.36
IBM 9370-60 M/A asst	VS 1.4.0 opt=3(Coded BLAS)	26	.46	1.48
micro VAX 3200/3500/3600	VMS v4.6(Coded BLAS)	27	.45	1.53
Prime P9755	f77 21.0 -OPT(Coded BLAS)	29	.42	1.63
IRIS 2400 Turbo/FPA	f77(Coded BLAS)	36	.34	2.04
Masscomp MC5600 wFPA	f77 v1.2 -O3(Coded BLAS)	31	.40	1.73
Celerity C1200	UNIX 4.2 bsd f77(Coded BLAS)	38	.32	2.15
Gould PN 6005	VTX/32 2.0 Fortran 77(Coded BLAS)	48	.26	2.67
Ridge Server/RF EFP	ROS/rf(Coded BLAS)	54	.23	3.03
VAX 11/785 FPA	VMS v4.5(Coded BLAS)	53	.23	2.99
DEC VAX 8250/8350	VMS v4.6(Coded BLAS)	58	.21	3.25
DEC VAX 8200/8300	VMS v4.5(Coded BLAS)	68	.18	3.81
IBM 9370-40 M/A asst	VS 1.4.0 opt=3(Coded BLAS)	67	.18	3.76
VAX 11/780 FPA	VMS v4.5(Coded BLAS)	72	.17	4.04
micro VAX II	VMS v4.5(Coded BLAS)	77	.16	4.29
IBM 9370-20 M/A asst	VS 1.4.0 opt=3(Coded BLAS)	82	.15	4.60
VAX 11/750 FPA	VMS v4.1(Coded BLAS)	83	.15	4.64
Apollo DN460/660	AEGIS 8.0 FTN(Coded BLAS)	111	.11	6.20

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
Masscomp MC500 w/FPP	3.1 Fortran(Coded BLAS)	132	.093	7.42
Opus 32.32	UNIX, f77 4.2 bsd(Coded BLAS)	173	.063	9.67
Sequent Balance 8000	DYNIX Fortran 2.4.4(Coded BLAS)	185	.066	10.4
Apollo DN320	AEGIS 8.0 FTN(Coded BLAS)	235	.052	13.2
Apollo DN550 FPA	AEGIS 8.0 FTN(Coded BLAS)	262	.047	14.7
VAX 11/725 FPA	VMS v4.1(Coded BLAS)	283	.043	15.8
VAX 11/730 FPA	VMS(Coded BLAS)	286	.043	16.0
Intel iPSC/d0 (1 processor)	NX 3.0(Coded BLAS)	434	.028	24.3
Apollo DN300	AEGIS 8.0 FTN(Coded BLAS)	1721	.0071	96.4

Table 3

Solving a System of Linear Equations

with LINPACK [a] in Half Precision [b] Using All Fortran

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
NEC SX-2	FORTRAN 77/SX(Rolled BLAS)	.28	44	.016
NEC SX-1	FORTRAN 77/SX(Rolled BLAS)	.33	37	.019
NEC SX-1E	FORTRAN 77/SX(Rolled BLAS)	.38	32	.021
NAS AS/XL V60	VAST/VS 1.4.1 opt=3	.58	21	.032
Amdahl 1400	77/VP V10L20(Rolled BLAS)	.64	19	.036
Amdahl 1200	77/VP V10L20(Rolled BLAS)	.63	19	.036
Amdahl 1100	77/VP V10L20(Rolled BLAS)	.69	18	.039
Fujitsu VP-200	Fortran 77(Rolled BLAS)	.69	18	.039
Siemens H120F	Fortran 77(Rolled BLAS)	.70	17	.039
Amdahl 500	77/VP V10L20(Rolled BLAS)	.75	16	.042
Fujitsu VP-100	Fortran 77(Rolled BLAS)	.75	16	.042
Hitachi S-810/20	FORT77/HAP(Rolled BLAS)	.78	16	.044
IBM 3090/180S VF	VS Fortran 2.3.0(Rolled BLAS)	.80	15	.045
Fujitsu VP-50	Fortran 77(Rolled BLAS)	.88	14	.049
IBM 3090/180E VF	VS 2.1.1 opt=3(Rolled BLAS)	.90	14	.050
Sperry 1100/90 ext w/ISP	UCS level 2	.89	14	.050
IBM 3090/180 VF	VS Fortran V2(Rolled BLAS)	.95	13	.053
CONVEX C-210 (1 proc)	Fortran 4.0(Rolled BLAS)	1.1	12	.060
Alliant FX/80 (8 proc)	FX v4.0.21(Rolled BLAS)	1.2	10.6	.0649
NAS AS/XL 60	VS 1.4.1 opt=3	1.2	10	.067
NAS AS/9160	VS 1.4.1 opt=3	1.2	10	.067
IBM 3090/150E VF	VS 2.1.1 opt=3(Rolled BLAS)	1.3	9.3	.073
IBM 3090/180S	VS Fortran 2.3.0(Rolled BLAS)	1.3	9.6	.071
IBM 3090/120E VF	VS 2.1.1 opt=3(Rolled BLAS)	1.4	8.5	.081
CONVEX C-130	Fortran 4.0(Rolled BLAS)	1.5	8.4	.081
Siemens 7890F	Fortran 77 V10.3	1.5	8.1	.084
IBM 3090/180E	VS 2.1.1 opt=3	1.6	7.8	.088
Alliant FX/80 (4 proc)	FX v4.0.21(Rolled BLAS)	1.7	7.2	.0956
IBM 3090/180	VS Fortran opt=3	1.7	7.1	.097
Fujitsu M-380	Fortran 77, opt=3	1.7	7.0	.098
Alliant FX/40 (4 proc)	FX v4.0.21(Rolled BLAS)	1.8	6.7	.102
Honeywell DPS90	ES F77V 1.0(Rolled BLAS)	1.8	6.7	.103
Siemens 7890G	Fortran 77 V10.3 opt=4	1.9	6.4	.108
IBM 3090/150E	VS 2.1.1 opt=3	2.0	6.2	.111
MIPS M/2000	f77	2.1	5.7	.117
CONVEX C-120	Fortran 4.0(Rolled BLAS)	2.2	5.5	.124
Amdahl 5860 HSFPF	H enhanced opt=3	2.2	5.5	.125
Amdahl 5860 HSFPF	VS Fortran opt=3	2.4	5.1	.135
Gould NP1	Fortran (Rolled BLAS)	2.4	5.1	.135
Alliant FX/4 (4 proc)	FX v4.0.21(Rolled BLAS)	2.5	4.9	.139
CONVEX C-1/XP	Fortran 1.6(Rolled BLAS)	2.9	4.3	.160
Alliant FX/40 (2 proc)	FX v4.0.21(Rolled BLAS)	2.9	4.2	.162
CONVEX C-1/XL	Fortran 1.6(Rolled BLAS)	3.0	4.1	.168
MIPS M120-5	UMIPS v.3 3.0 f771.31 -O	3.1	3.9	.174
NAS 8093 w/HSA	VS 1.4.0 opt=3	3.1	3.9	.175

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
MIPS M/1000	UMIPS 2.03 f77 1.30 -O	3.4	3.6	.190
IBM 3090/120E	VS 2.1.1 opt=3	3.7	3.3	.207
MIPS M/800	F77 1.30	4.1	3.0	.230
Sperry 1100/90	FTN opt=ZEO	4.4	2.8	.248
Amdahl 470 V/8	H enhanced opt=3	4.4	2.8	.246
Amdahl 470 V/8	VS Fortran opt=3	4.5	2.7	.254
Sperry 1100/90 ext	UFTN	5.0	2.5	.279
IBM 3081 K	H enhanced opt=3	5.1	2.4	.283
Alliant FX/80 (1 proc)	FX v4.0.21(Rolled BLAS)	5.2	2.3	.292
Alliant FX/40 (1 proc)	FX v4.0.21(Rolled BLAS)	5.2	2.3	.294
Numerix NMX-432	4540 FDS Fortran	5.5	2.2	.310
IBM 3081 K	VS Fortran opt=3	5.6	2.2	.311
NAS 8093	VS 1.4.0 opt=3	6.0	2.1	.333
IBM 3033	VS Fortran	6.3	1.9	.353
Siemens 7570-P	For1 1.6A	6.3	1.9	.355
Prime P6350	f77 21.0 -opt	6.5	1.9	.365
Honeywell DPS 8/88	FR7X	6.6	1.8	.371
IBM 3081 D	VS Fortran opt=3	6.7	1.8	.376
ELXSI 6420	Unix 5.3 f77 -Oskm	6.9	1.8	.385
ICL 3980 w/FPU	FORTRAN77 PLUS V10.02	7.60	1.6	.426
SUN 4/260	f77 -O sys4-beta2	7.7	1.6	.430
Alliant FX/4 (1 proc)	FX v4.0.21(Rolled BLAS)	7.3	1.7	.411
Alliant FX/1	FX v4.0.21(Rolled BLAS)	8	1.5	.465
MIPS M800 w/R2010 FP	f77 1.10	8.0	1.5	.450
DEC VAX 8550/8700/8800	VMS 4.5	9.1	1.4	.509
ELXSI 6420	Fortran 5.14 opt=10	9.2	1.3	.516
DEC VAX 8650	VMS v4.5	9.8	1.3	.549
Concurrent 3280XP	Fortran VII,Z 8.1	9.9	1.2	.552
IBM 4381-23	VS 2.1.1 opt=3	10	1.2	.580
IBM 9370-90	VS Fortran 1.3.0 opt=3	11	1.1	.625
Harris HCX-9	hf77 -O3	11	1.1	.633
IBM 4381-13	VS Fortran 1.4.0 opt=3	12	1.1	.644
Pyramid 9810	OSx 4.0	12	1.0	.667
Gould PN 9005	VTX/32 2.0 Fortran 77	12	1	.683
Sperry 7000	4.2	13	.96	.717
CCI Power 6/32 w/fpa	UNIX 4.2 bsd f77	13	.94	.733
Harris HCX-7 w/fpp	f77 1.0	13	.94	.733
DEC VAX 8530	VMS v4.6	13	.93	.738
Siemens 7860E	Fortran 77 V10.3	14	.90	.763
Mentor Graphics Computer	fortran	14	.89	.772
IBM 4381-22	VS 2.1.1 opt=3	14	.87	.793
SUN-3/260 + FPA	3.2 f77 -O -ffpa	14	.86	.800
IBM 4381 MG2	VS Fortran opt=3	14	.86	.801
Prime P9955II	f77 21.0	14	.86	.802
IBM 4381-12	VS Fortran 1.4.0 opt=3	14	.85	.805
DEC VAX 8600	VMS v4.5	15	.84	.818
Sperry 1100/80 w/SAM	FTN opt=ZEO	15	.83	.830
DEC VAX 8500	VMS v4.5	15	.80	.858
Gould 32/9705 w/MACC	MPX 3.3 fort+ 4.3	16	.76	.908
Apollo DN5xxT FPX	DOMAIN/IX SR9.7 opt 4	17	.72	.960
Gould 9050 w MACC	UNIX 4.2bsd f77	17	.70	.980
Gould PN9000	UNIX	17	.69	1.0

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
DEC VAX 6210 (1 proc.)	VMS v5.0	18	.69	.993
Harris H1200	VOS 4.1 opt g	18	.68	1.01
micro VAX 3200/3500/3600	VMS v4.6	19	.66	1.04
Ridge 3200 Model 90	ROS/rf	19	.66	1.05
SUN-3/160 + FPA	3.2 f77 -O -ffpa	20	.62	1.10
HP 9000 Series 840	HP-UX 14.3	21	.58	1.19
IBM 9370-60	VS Fortran 1.4.0 opt=3	21	.58	1.19
Gould PN9080	UTX/32	21	.57	1.20
Opus Series 300pm 30 MHz	UNIX Greenhills	21	.57	1.20
Harris H1000	VOS 3.3 opt g	22	.57	1.21
CONCEPT 32/8750	UTX/32	23	.54	1.27
Gould 32/9705	Fortx 32 version 2.0	23	.54	1.27
Kontron KSM w/WTL1167	UNIX f77 SVS 23	.54	1.27	3.70
IBM 4381-21	VS 2.1.1 opt=3	23	.52	1.31
Sperry 1100/80	FTN opt=ZEO	24	.52	1.32
IBM 4381 MG1	VS Fortran opt=3	24	.51	1.33
Celerity C1230	UNIX 4.2 bsd f77	24	.51	1.35
NORSK DATA ND-570/2	Fortran-500-E	25	.50	1.38
Masscomp MC5600 68020 w/fpa	f77 v1.2 -O3	25	.50	1.38
Prime P9755	f77 21.0	26	.47	1.47
IBM 4381-11	VS Fortran 1.4.0 opt=3	28	.43	1.58
CSA w/T800C-20	Fortran 3L	29	.43	1.60
IBM 4361 MG5	VS Fortran opt=3	29	.42	1.65
IBM RT-PC	2.1.1	30	.40	1.70
Data General MV/10000	f77 opt level 2	31	.39	1.75
IRIS 2400 Turbo/FPA	f77	31	.40	1.72
DEC VAX 11/785 FPA	VMS v4.5	31	.40	1.72
Pyramid 98xe	OSx 4.0	32	.38	1.80
Prime 9950	F77 19.4.2	36	.34	2.00
IBM RT PC 6150/115 fpa2	f77	36	.34	2.00
Gould PN 6005	VTX/32 2.0 Fortran 77	37	.33	2.09
Honeywell DPS 8/70	FR7X	40	.31	2.22
DEC VAX 11/785 FPA	UNIX 4.2 bsd f77	40	.31	2.27
Celerity C1200	UNIX 4.2 bsd f77	40	.30	2.27
IBM 370/158	H opt=3	42	.29	2.35
Ridge Server/RT EFP	ROS/rf	43	.29	2.40
IBM 9370-40	VS Fortran 1.4.0 opt=3	43	.29	2.41
Concurrent 3252	OS 6.2.4 fortran z	45	.27	2.50
DEC VAX 8250/8350	VMS v4.6	45	.27	2.51
NORSK DATA ND-560	Fortran-500	45	.27	2.54
NORSK DATA ND-500	Fortran-500-E	46	.27	2.58
DEC KL-20	F20	46	.27	2.59
IBM 370/158	VS Fortran opt=3	46	.26	2.60
Ridge 32/130	ROS 3.3/RISC	47	.26	2.64
DEC VAX 11/780 FPA	VMS v4.5	49	.25	2.75
Sperry 1100/60	FTN opt=ZEO	49	.25	2.77
ICL 2988	f77 OPT=2	50	.25	2.79
Concurrent 3242	OS 32 v7.2 f77	51	.24	2.88
Kontron KSM/386	UNIX f77 SVS 2.8	52	.24	2.92
Harris 800	Fortran 77	53	.23	2.99
DEC VAX 8200/8300	VMS 4.3	55	.22	3.10
IBM 4341 MG10	VS Fortran opt=3	57	.22	3.18

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
IBM 9370-20	VS Fortran 1.4.0 opt=3	58	.21	3.23
Prime P2755	f77 rev 20.2.B2 -opt	59	.21	3.33
Tektronix 4315 w/68882	UTEK f77	62	.20	3.45
Honeywell 6080	Y	62	.20	3.46
Pyramid 90X FPA	UNIX 4.2 bsd f77	63	.20	3.50
CONCEPT 32/6750	UTX/32	65	.19	3.63
DEC VAX 11/780 FPA	UNIX 4.3 BSD f77 -O	65	.19	3.68
Ridge 32/110	ROS 3.3/RISC	67	.18	3.73
DEC VAX 11/750 FPA	VMS v4.1	67	.18	3.75
Data General MV/8000	f77 opt level 2	69	.18	3.84
DEC micro VAX II	VMS v4.5	72	.17	4.10
DEC VAX 11/780	VMS v4.1	74	.17	4.13
Concurrent 3230	OS 6.2.2 fortran 5.2	76	.16	4.26
Apollo DN4000	DOMAIN/IX SR9.7 opt 4	75	.16	4.20
Prime P2450	f77 rev 20.2.B2 -opt	78	.16	4.37
ENCORE Multimax NS32332	f77	81	.15	4.53
Prime 750	Primos f77 v19.1	89	.14	5.00
Tektronix 4315 w/68881	UTEK f77	91	.13	5.10
DEC VAX 11/750 FPA	UNIX 4.2 bsd f77	91	.13	5.12
HP 9000 Series 350	HP-UX, f77 5.2	94	.13	5.26
Definicon DSI-780	SVS Fortran (MSDOS)	94	.13	5.27
SUN-3/260, 20 MHz 68881	3.2 f77 -O -f68881	97	.13	5.40
Apollo DN590	DOMAIN/IX SR9.7 opt 4	109	.11	6.10
Prime 850	Primos	97	.13	5.41
Masscomp MC5600 68881	f77 v1.2 -O3	110	.11	6.14
Masscomp MC500 w/FPP	3.1 Fortran	111	.11	6.23
Harris HS-20 w/FPP	Fortran 77 3.1	114	.11	6.38
SUN-3/160, 16.7 MHz 68881	3.2 f77 -O -f68881	112	.11	6.20
Apollo DN460/660	AEGIS 8.0 FTN	118	.10	6.60
micro VAX II	f77 Ultrix 1.1	121	.10	6.77
HP 9000 Series 500	Fortran 1.7	125	.098	7.00
HP 9000 Series 330	HP-UX, f77 5.2	125	.098	7.02
Prime P2350	f77 rev 20.2.B.2	127	.097	7.09
SUN-3/50, 16.7 MHz 68881	3.2 f77 -O -f68881	133	.093	7.40
Pyramid 90X	UNIX 4.2 bsd f77	134	.092	7.50
DEC VAX 11/750	VMS v4.1	138	.089	7.71
HP 9000 Series 320	HP-UX, f77 5.2	139	.088	7.80
IBM 4331 MG2	H opt=3	140	.088	7.84
Apollo DN3000	DOMAIN/IX SR9.7 opt 4	173	.079	8.66
Apple Mac/Levco Prodigy 4	ABSOFT MacFort 020	157	.078	8.80
Sequent Balance 8000	DYNIX Fortran 2.4.4	162	.075	9.10
Definicon DSI-32/10	GreenHills f77 (MSDOS)	175	.070	9.82
ENCORE Multimax	f77	176	.670	9.87
DEC VAX 11/750	UNIX 4.1 bsd f77	204	.060	11.4
Masscomp MCS-541 w/FPB	Fortran 3.1	227	.054	12.7
ATT 3B20 FP	UNIX V 2.0/4	231	.053	12.9
Burroughs 6700	H	234	.052	13.1
DEC VAX 11/725 FPA	VMS v4.1	236	.052	13.2
Opus 32.32	UNIX, f77 4.2 bsd	240	.051	13.4
Acorn Cambridge	fortran	250	.049	14.0
Prime 2250	Fortran 77	258	.048	14.5
DEC VAX 11/730 FPA	VMS	259	.047	14.5

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
SUN-2/50 + SKY FFP	f77 -O -fsky 3.0	266	.046	14.9
micro VAX I	VMS	272	.045	15.2
IBM PC-AT/370	VS Fortran opt=3	279	.044	15.6
Apollo DN320	AEGIS 8.0 FTN	277	.044	15.5
Chas. River Data 6835+SKY	SVS Fortran 77	284	.043	15.9
IBM PC-XT/370	H opt=3	303	.040	17.0
DEC KA-10	F40	305	.040	17.1
Apollo DN550 FPA	AEGIS 8.0 FTN	305	.040	17.1
Canaan	VS	306	.040	17.1
IBM RT PC Model 20	f77	368	.033	20.6
Apollo DN 420 PEB	AEGIS 7+ FTN	394	.031	22.1
Olivetti M28 w/80287	PROFORT 1.0	670	.018	37.6
Chas. River Data 6835	SVS Fortran 77	770	.016	43.1
IBM AT w/80287	PROFORT 1.0	891	.013	49.8
Cadtrak DS1/8087	Intel Fortran 77	893	.013	50.0
IBM PC w/8087	PROFORT 1.0	906	.013	50.8
Apollo DN300	AEGIS 8.0 FTN	944	.013	53.0
SUN-2/50	f77 -O -fsoft 3.0	983	.013	55.0
Masscomp MC500	3.1 Fortran	1037	.012	58.1
IBM PC w/8087	Microsoft 3.1	1071	.011	60.0
HP 9000 Series 200	HP-UX	1196	.010	67.0
SUN	UNIX, f77 no opt	1298	.0094	72.7
Apple Macintosh	ABSOFT 2.0b	1723	.0071	96.5
Tandy 2000	Microsoft 3.13	3763	.0033	211.
IBM PC	Microsoft 3.1	21875	.00056	1225.
Apple III	Pascal	50232	.00024	2813.

Table 4

Solving a System of Linear Equations with LINPACK [a] in Half Precision [b] Using Coded BLAS

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
ETA10-E (1 proc. 10.5ns)	ETAV/FTN200(Coded BLAS)	.18	67	.010
NAS AS/XL V60	VAST/VS 1.4.1 opt=3(Coded BLAS)	.29	42	.016
Amdahl 1400	77/VP V10L20(Coded BLAS)	.39	31	.022
Amdahl 1200	77/VP V10L20(Coded BLAS)	.41	30	.023
ETA10-P (1 proc. 24ns)	ETAV/FTN200(Coded BLAS)	.41	29	.023
CDC Cyber 205 (4-pipe)	FTN200 2.1.6(Coded BLAS)	.46	27	.026
Amdahl 1100	77/VP V10L20(Coded BLAS)	.47	26	.027
Amdahl 500	77/VP V10L20(Coded BLAS)	.52	23	.029
CDC Cyber 205 (2-pipe)	FTN200 2.1.6(Coded BLAS)	.53	23	.030
IBM 3090/180S VF	VS Fortran 2.3.0(Coded BLAS)	.64	19	.036
NAS 9160	VS opt=3 (Coded BLAS)	.70	17	.039
IBM 3090/180E VF	VS 2.1.1 opt=3(Coded BLAS)	.73	17	.041
Alliant FX/80 (8 proc)	FX v4.0.21(Coded BLAS)	.86	14	.0480
IBM 3090/150E VF	VS 2.1.1 opt=3(Coded BLAS)	.94	13	.053
IBM 3090/120E VF	VS 2.1.1 opt=3(Coded BLAS)	1.1	12	.059
CONVEX C-210 (1 proc)	Fortran 4.0(Coded BLAS)	1.1	12	.060
Alliant FX/80 (4 proc)	FX v4.0.21(Coded BLAS)	1.2	9.9	.0694
Alliant FX/40 (4 proc)	FX v4.0.21(Coded BLAS)	1.3	9.1	.0753
CONVEX C-130	Fortran 4.0(Coded BLAS)	1.5	8.4	.081
MIPS M/2000	f77(Coded BLAS)	1.7	7.2	.096
Alliant FX/4 (4 proc)	FX v4.0.21(Coded BLAS)	2.0	6.2	.111
Alliant FX/40 (2 proc)	FX v4.0.21(Coded BLAS)	2.1	5.7	.120
CONVEX C-120	Fortran 4.0(Colled BLAS)	2.2	5.5	.124
Gould NP1	Fortran (Coded BLAS)	2.4	5.2	.132
CONVEX C-1/XP	Fortran 1.6(Coded BLAS)	2.5	4.9	.139
CONVEX C-1/XL	Fortran 1.6(Coded BLAS)	2.5	4.9	.139
MIPS M120-5	UMIPS v.3 3.0 f771.31 -O(Coded BLAS)	2.6	4.8	.143
MIPS M/1000 w/R2010 FP	f77 1.21(Coded BLAS)	2.9	4.3	.160
Numerix NMX-432	AR Fortran(Coded BLAS)	3.5	3.5	.199
Alliant FX/80 (1 proc)	FX v4.0.21(Coded BLAS)	3.8	3.2	.213
Alliant FX/40 (1 proc)	FX v4.0.21(Coded BLAS)	3.8	3.2	.213
MIPS M800 w/R2010 FP	f77 1.10(Coded BLAS)	5.2	2.4	.290
Prime P6350	f77 21.0(Coded BLAS)	5.5	2.3	.305
Alliant FX/4 (1 proc)	FX v4.0.21(Coded BLAS)	5.8	2.1	.325
Mentor Graphics Computer	fortran(Coded BLAS)	5.8	2.1	.326
ELXSI 6420	Fortran 5.14 opt=10(Coded BLAS)	6.1	2.0	.342
DEC VAX 8650	VMS v4.5(Coded BLAS)	6.5	1.9	.365
Alliant FX/1	FX v4.0.21(Coded BLAS)	7	1.7	.393
DEC VAX 8550/8700/8800	VMS v4.5(Coded BLAS)	7.4	1.7	.416
Harris HCX-9	hf77 -O3(Coded BLAS)	7.4	1.6	.417
Mitsubishi MX/3000 w/sp	Fortran 77(Coded BLAS)	7.9	1.6	.445
Gould PN 9005	VTX/32 2.0 Fortran 77(Coded BLAS)	8.9	1.4	.497
Gould PN9000	UNIX(Coded BLAS)	9.2	1.3	.520
DEC VAX 8600	VMS v4.5(Coded BLAS)	10	1.2	.558
DEC VAX 8530	VMS v4.6(Coded BLAS)	11	1.1	.614

Computer	OS/Compiler[c]	Ratio[d]	MFLOPS[e]	Time secs
NORSK DATA ND-570/2	Fortran-500-E(Coded BLAS)	12	1.0	.678
Prime P9955II	f77 21.0(Coded BLAS)	12	1.0	.680
Harris H1200	VOS 4.1 opt g(Coded BLAS)	12	.99	.693
DEC VAX 8500	VMS v4.5(Coded BLAS)	13	.96	.715
DEC VAX 6210 (1 proc.)	VMS v5.0 (Coded BLAS)	14	.90	.759
Harris H1000	VOS 3.3 opt g(Coded BLAS)	15	.83	.825
Ridge 3200 Model 90	ROS/rf(Coded BLAS)	15	.81	.849
micro VAX 3200/3500/3600	VMS v4.6(Coded BLAS)	15	.79	.866
HP 9000 Series 840	HP-UX 14.3(Coded BLAS)	17	.73	.940
Celerity C1230	UNIX 4.2 bsd f77(Coded BLAS)	17	.72	.950
Masscomp MC5600 68020wFPA	f77 v1.2 -~rO3(Coded BLAS)	19	.66	1.04
Prime P9755	f77 21.0(Coded BLAS)	22	.57	1.22
IRIS 2400 Turbo/FPA	f77(Coded BLAS)	23	.54	1.26
DEC VAX 11/785 FPA	VMS v4.5(Coded BLAS)	23	.53	1.30
Celerity C1200	UNIX 4.2 bsd f77(Coded BLAS)	28	.44	1.55
Gould PN 6005	VTX/32 2.0 Fortran 77(Coded BLAS)	28	.44	1.57
DEC VAX 8250/8350	VMS v4.6(Coded BLAS)	33	.37	1.86
DEC VAX 11/780 FPA	VMS v4.6(Coded BLAS)	35	.35	1.94
Ridge Server/RT EFP	ROS/rf(Coded BLAS)	35	.35	1.95
DEC VAX 8200/8300	VMS v4.5(Coded BLAS)	40	.31	2.22
DEC VAX 11/750 FPA	VMS v4.1(Coded BLAS)	51	.24	2.83
DEC micro VAX II	VMS v4.5(Coded BLAS)	56	.22	3.12
Masscomp MC500 w/FPP	3.1 Fortran(Coded BLAS)	72	.17	4.02
Apollo DN460/660	AEGIS 8.0 FTN(Coded BLAS)	99	.12	5.60
Sequent Balance 8000	DYNIX Fortran 2.4.4(Coded BLAS)	148	.083	8.31
Apollo DN320	AEGIS 8.0 FTN(Coded BLAS)	150	.082	8.40
Apollo DN550 FPA	AEGIS 8.0 FTN(Coded BLAS)	162	.076	9.10
DEC VAX 11/725 FPA	VMS v4.1(Coded BLAS)	186	.066	10.4
DEC VAX 11/730 FPA	VMS(Coded BLAS)	205	.060	11.5
Opus 32.32	UNIX, f77 4.2 bsd(Coded BLAS)	212	.058	11.9
COMPAQ PC/8087	Microsoft 3.13(Coded BLAS)	591	.021	33.1
Apollo DN300	AEGIS 8.0 FTN(Coded BLAS)	924	.013	51.8

[a] LINPACK routines *SGEFA* and *SGESL* were used for single precision and routines *DGEFA* and *DGESL* were used for double precision. These routines perform standard *LU* decomposition with partial pivoting and backsubstitution.

[b] *Full Precision* implies the use of (approximately) 64 bit arithmetic, e.g. CDC single precision or IBM double precision. *Half Precision* implies the use of (approximately) 32 bit arithmetic, e.g. IBM single precision.

[c] *OS/Compiler* refers to the operating system and compiler used, (Coded BLAS) refers to the use of assembly language coding of the BLAS, and (Rolled BLAS) refers to a Fortran version with, single statement, simple loops [2].

[d] *Ratio* is the number of times faster or slower a particular machine configuration is when compared to the CRAY-1S using a Fortran coding for the BLAS in full precision as run in 1983 with CFT 1.12.

[e] *MFLOPS* is a rate of execution, the number of million floating point operations completed per second. For solving a system of n equations, approximately $2/3n^3 + 2n^2$ operations are performed (we count both additions and multiplications).

$$Unit = 10^6 Time / (\frac{100^3}{3} + 100^2).$$

The execution times for the LINPACK benchmark in Tables 1 and 2 were gathered in the following way: The LINPACK code (SEGFA and SGESL in single precision and DGEFA and DGESL in double precision) was not modified in any way. In particular, no changes to the source statements or changes or additions to the comments were allowed. Only the BLAS were allowed to change, in two ways. First, in some cases, the Fortran version of the BLAS was replaced and implemented in assembly language for the specific machine; these are indicated by the annotation "(Coded BLAS)". Second, in the case where a Fortran implementation of the BLAS was used on vector machines the loops were usually rolled; these are indicated by the annotation "(Rolled BLAS)". (In the Fortran implementation of the BLAS the loops are unrolled to provided for better performance on scalar machines. On vector machines this technique usually results in poor performance since the compiler cannot recognize the vector loop.)

The same matrix was used to solve the system of equations. The results were checked for accuracy by calculating a residual for the problem, $|| Ax - b || / (|| A || || x ||)$. The timing program is available on request.

Performance of Large Scientific Computers in a Fortran Environment

The LINPACK routines used to generate the timings in the previous table do not reflect the true performance of "advanced scientific computers". A different implementation of the solution of linear equations, presented in a report by Dongarra and Eisenstat [3], better describes the performance on such machines. That algorithm is based on matrix-vector operations rather than just vector operations. This produces a program that has a high level of modularity or larger granularity, having the potential for better performance across a wide range of machines, especially on high performance computers. The number of floating point operations required and the roundoff errors produced by both algorithms are exactly the same, only the way in which the matrix elements are accessed is different. As before, a Fortran program was run and the time to complete the solution of equations for a matrix of order 300 is reported.

Note that these numbers are for a problem of order 300 and all runs are for full precision.

The table was compiled over a period of time. Subsequent software and hardware changes to a computer system may alter the timing to some extent.

Table 5

Solving a System of Linear Equations

Using the Vector Unrolling Technique

Computer	OS/Compiler[a]	MFLOPS[b]	Time secs
CRAY Y-MP/832 (4 proc)	CFT77 2.1 (Coded BLAS)	561	.032
CRAY Y-MP/832 (3 proc)	CFT77 2.1 (Coded BLAS)	512	.035
CRAY 2S (4 proc.)	CFT77 2.1(Coded BLAS)	455	.039
CRAY X-MP/4 (4 proc 8.5ns)	CFT77 2.1 (Coded BLAS)	446	.040
Hitachi S-820/80	Fortran 77 HAP	440	.041
CRAY 2S (3 proc.)	CFT77 2.1(Coded BLAS)	430	.042
CRAY Y-MP/832 (2 proc)	CFT77 2.1 (Coded BLAS)	413	.044
CRAY X-MP/4 (3 proc 8.5ns)	CFT77 2.1 (Coded BLAS)	382	.047
CRAY 2S (2 proc.)	CFT77 2.1(Coded BLAS)	371	.049
NEC SX-2	FORTRAN 77/SX	347	.052
CRAY X-MP/4 (2 proc 8.5ns)	CFT77 2.1 (Coded BLAS)	307	.059

Computer	OS/Compiler[a]	MFLOPS[b]	Time secs
Amdahl 1400	77/VP V10L20(Coded BLAS)	276	.065
CRAY 2S (1 proc.)	CFT77 2.1(Coded BLAS)	275	.066
CRAY Y-MP/832 (1 proc)	CFT77 2.1 (Coded BLAS)	261	.0689
Amdahl 1200	77/VP V10L20(Coded BLAS)	249	.072
NEC SX-1	FORTRAN 77/SX	224	.080
Fujitsu VP-200	Fortran 77(Comp directive)	220	.083
Amdahl 1400	77/VP V10L20	202	.089
Fujitsu VP-400	F77/VP V10L30	197	.091
Amdahl 1200	77/VP V10L20	194	.072
CRAY X-MP/4 (1 proc 8.5ns)	CFT77 2.1 (Coded BLAS)	188	.096
CRAY Y-MP/832 (1 proc)	CFT77 2.1	187	.096
Amdahl 1100	77/VP V10L20(Coded BLAS)	183	.098
Fujitsu VP-200	Fortran 77	183	.099
ETA10-E (1 proc.)	ETAV,FTN200(Coded MV routines)	182	.097
Fujitsu VP-100	Fortran 77(Comp directive)	159	.113
CRAY X-MP/14se	CFT77 2.0(Coded BLAS)	158	.114
Hitachi S-810/20	FORT77/HAP	158	.115
Amdahl 1100	77/VP V10L20	155	.116
NEC SX-1E	FORTRAN 77/SX	147	.122
Hitachi S-810/10	Fortran 77 HAP	146	.123
Fujitsu VP-100	Fortran 77	139	.129
CRAY X-MP/4 (1 proc 8.5ns)	CFT77 2.1	135	.133
CRAY 2S (1 proc.)	CFT77 2.1	131	.137
CRAY X-MP/14se	CFT77 2.0	114	.157
Amdahl 500	77/VP V10L20(Coded BLAS)	110	.163
ETA10-Q (1 proc.)	ETAV,FTN200(Coded MV routines)	101	.178
Fujitsu VP-50	Fortran 77(Comp directive)	100	.180
CRAY-2 (1 proc.)	CFT 2.70	93	.195
Amdahl 500	77/VP V10L20	90	.199
Fujitsu VP-50	Fortran 77	84	.214
CRAY 1-M	CFT(Coded ISAMAX)	83	.215
ETA10-P (1 proc.)	ETAV,FTN200(Coded MV routines)	80	.225
CRAY 1-S	CFT(Coded ISAMAX)	76	.236
CDC Cyber 205	ftn 200 opt=1(Coded MV routines)	71	.253
CRAY 1-M	CFT	69	.259
CRAY 1-S	CFT	66	.273
Sperry 1100/90 ext w/ISP	UFTN(Coded MV routines)	45	.396
IBM 3090/180S VF	VS Fortran 2.3.0(Coded BLAS)	44	.390
CONVEX C-210 (1 proc)	Fortran 4.0(Coded MV routines)	41	.446
SCS-40	CFT 1.13(Coded MV routines)	37	.496
Sperry 1100/90 ext w/ISP	UFTN	34	.532
Alliant FX/80 (8 proc)	FX v4.0.21 (coded MV)	33	.542
FPS-264 (M64/60)	F02, F77(Coded MV routines)	33	.550
IBM 3090/180E VF	VS 2.1.1(Coded MV routines)	33	.553
CONVEX C-210 (1 proc)	Fortran 4.0	32	.562
IBM 3090/180S VF	VS Fortran 2.3.0	30	.610
CONVEX C-130	Fortran 4.0(Coded MV routines)	29	.613
SCS-40	CFT 1.13	27	.665
IBM 3090/180 VF	VS Fortran V2(Coded MV routines)	27	.673
IBM 3090/150E VF	VS 2.1.1(Coded MV routines)	27	.670
FPS-164/364 + 4 MAX	E, F77 (Coded MV routines)	26	.700
CONVEX C-130	Fortran 4.0	24	.762

Computer	OS/Compiler[a]	MFLOPS[b]	Time secs
FPS-164/364 + 3 MAX	E, F77 (Coded MV routines)	24	.770
IBM 3090/180E VF	VS 2.1.1	22	.844
Alliant FX/80 (4 proc)	FX v4.0.21 (coded MV)	21	.848
NAS 9160	VS opt=3(Coded MV routines)	20	.880
FPS-164/364 + 2 MAX	E, F77 (Coded MV routines)	20	.890
FPS-264 (M64/60)	F02 APFTN64 OPT=4	20	.900
CyperPlus	CPFTN 1.1-07 (Coded MV routines)	18	.999
IBM 3090/180 VF	VS Fortran V2	18	1.0
IBM 3090/150E VF	VS 2.1.1	18	1.0
FPS-164/364 + 1 MAX	E, F77 (Coded MV routines)	15	1.8
Alliant FX/80 (8 proc)	FX v3.1.33	15	1.18
CONVEX C-120	Fortran 4.0(Coded MV routines)	15	1.21
CONVEX C-1/XP	Fortran 2.0(Coded MV routines)	15	1.2
IBM 3090/120E VF	VS 2.1.1(Coded MV routines)	14	1.2
CONVEX C-1/XL	Fortran 1.6(Coded MV routines)	14	1.3
Alliant FX/40 (4 proc)	FX v4.0.21 (coded MV)	13	1.38
Alliant FX/80 (4 proc)	FX v4.0.21	12	1.5
CONVEX C-120	Fortran 4.0	12	1.55
Alliant FX/4 (4 proc)	FX v4.0.21 (coded MV)	12	1.56
FPS-264/20 (M64/50)	F02 APFTN64 OPT=4	11	1.6
IBM 3090/120E VF	VS 2.1.1	11	1.7
CONVEX C-1/XP	Fortran 2.0	8.9	2.0
CONVEX C-1/XL	Fortran 1.6	8.7	2.1
FPS 164/364 (M64/40)	E, opt=3(Coded MV routines)	8.7	2.1
Alliant FX/40 (4 proc)	FX v3.1.33	8.4	2.14
Alliant FX/80 (1 proc)	FX v4.0.21 (coded MV)	7.0	2.56
Alliant FX/4 (4 proc)	FX v3.1.33	6.9	2.6
NAS 9060	VS opt=2	6.9	2.6
FPS (M64/30)	F02, APFTN464	5.7	3.1
CDC Cyber 170/750	fortran	5.4	3.4
FPS-164/364 (M64/40)	F02 APFTN64 OPT=4	5.1	3.5
Alliant FX 40 (1 proc)	FX v4.0.21 (coded MV)	5.1	3.53
Alliant FX/80 (1 proc)	FX v3.1.33	4.5	.403
Alliant FX/4 (1 proc)	FX v4.0.21 (coded MV)	4.4	4.03
IBM 370/195	VS opt=2	4.4	4.1
CyperPlus	CPFTN 1.1-07	3.3	5.6
Alliant FX/40 (1 proc)	FX v3.1.33	3.5	5.13
Alliant FX/1	FX v4.0.21 (coded MV)	2.7	6.7
IBM 4381-24 (2 proc) M/A assist	VS 2.1.1(Coded MV)	2.6	6.8
Alliant FX/4 (1 proc)	FX v3.1.33	2.6	7.0
IBM 3033	VS opt=2	2.5	7.1
IBM 4381-14 (2 proc M/A assist)	VS 2.1.1 (Coded MV routines)	2.3	7.8
IBM 4381-24 (2 proc)	VS 2.1.1(Coded MV)	2.0	9.0
Alliant FX/1	FX v3.1.33	1.8	10
IBM 4381-14 (2 proc)	VS 2.1.1 (Coded MV routines)	1.8	10.
Seimens 7570		1.7	10.4
Mentor Graphics Computer	fortran	1.5	12.
IBM 4381-13 (1 proc M/A assist)	VS 2.1.1 (Coded MV routines)	1.4	13.
IBM 4381-23 (1 proc M/A assist)	VS 2.1.1 (Coded MV)	1.1	16
IBM 4381-23 (1 proc)	VS 2.1.1 (Coded MV)	1.1	16
IBM 4381-13 (1 proc)	VS 2.1.1 (Coded MV routines)	1.0	18.
ICL 3980 w/FPU	FORTRAN77 PLUS V10.02	1.5	12

Computer	OS/Compiler[a]	MFLOPS[b]	Time secs
SUN 4/260	f77 -O sys4-beta2	1.1	16
Encore NS32332	f77 opt	.12	153.
VAX 11/780 FPA	UNIX xf77	.11	177.

Comments:

[§] These timings are for four processors with manual changes to use parallel features.

[‡] These timings are for two processors with manual changes to use parallel features.

[†] These timings are for one processor of an X-MP-2.

The major difference between the CRAY 1-M and CRAY 1-S is in the memory speed, the CRAY 1-M having slower memory. The timings show the CRAY 1-M to be faster than the CRAY 1-S. After much discussion and examination of the generated assembly language code it was determined that, in fact, the CRAY 1-M was faster for this program. The code generated by the compiler causes the CRAY 1-S to miss a chain-slot. On the CRAY 1-M, because of slower memory, the chain-slot is not missed, thus the faster execution time.

[a] *OS/Compiler* refers to the operating system and compiler used, (Coded ISAMAX) refers to the use of assembly language coding of the BLAS ISAMAX and *Comp Directive* refers to the use of compiler directives in the matrix vector routines.

[b] *MFLOPS* is a rate of execution, the number of million floating point operations completed per second. For solving a system of n equations, $2/3n^3 + 2n^2$ operations are performed (we count both additions and multiplications).

Toward Peak Performance

In response to many requests, we have collected the results of solving a system of equations of order 1000. The difference between this performance and the previous results listed in this paper is that the manufacturer is allowed to use any algorithm to solve the problem.

The key to using a high-performance computer effectively is to avoid unnecessary memory references. In most computers, data flows from memory into and out of registers and from registers into and out of functional units, which perform the given instructions on the data. Algorithm performance can be dominated by the amount of memory traffic rather than by the number of floating-point operations involved. The movement of data between memory and registers can be as costly as arithmetic operations on the data. This provides considerable motivation to restructure existing algorithms and to devise new algorithms that minimize data movement.

Along these lines there has been much activity in the past few years involving redesign of some of the basic routines in linear algebra. A number of researchers have demonstrated the effectiveness of block algorithms on a variety of modern computer architectures with vector-processing or parallel-processing capabilities, on which potentially high performance can easily be degraded by excessive transfer of data between different levels of memory (vector registers, cache, local memory, main memory, or solid-state disks). This redesign has led to the development of algorithms that are based on matrix-vector and matrix-matrix techniques.

This approach to software construction is well suited to computers with a hierarchy of memory and true parallel-processing computers. For those architectures it is often preferable to partition the matrix or matrices into blocks and to perform the computation by matrix-matrix operations on the blocks. By organizing the computation in this fashion we provide for full reuse of data while the block is held in cache or local memory. This approach avoids excessive movement of data to and from memory and gives a *surface-to-volume* effect for the ratio of operations to data movement, i.e. $O(n^3)$ operations to $O(n^2)$ data movement. In addition, on architectures that provide for parallel processing, parallelism can be exploited in two ways: (1) operations on distinct blocks may be performed in parallel; and (2) within the operations on each block, scalar or vector operations may be performed in parallel. For a description of blocked implementation for some standard algorithms in

linear algebra see [4]. In the following benchmark many of the vendors use a version of LU decomosition which minimizes memory traffic and is based on these matrix-matrix ideas.

The only restriction in running this benchmark program is that the driver program (supplied by the author of this paper) be run to ensure that the same problem is solved. The driver program verifies that the answer is correct and computes total number of operations to solve the problem (independent of the method) as $\frac{2n^3}{3} + 2n^2$, where $n = 1000$. The following table contains the theoretical peak performance figures for each of the machines in terms of MFLOPS. These numbers are presented for comparison purposes only. The manufacturer usually refers to peak performance when describing a system. This peak performance is arrived at by counting the number of floating-point additions and multiplications (full precision) that can be completed during a period of time, usually the cycle time of the machine. As an example, the CRAY-1 has a cycle time of 12.5 nsec. During a cycle the results of both an addition and a multiplication can be completed

$$\frac{2\ operations}{1\ cycle} * \frac{1\ cycle}{12.5nsec} = 160MFLOPS.$$

By peak theoretical performance we mean only that the manufacturer guarantees that programs will not exceed these rates, sort of a *speed of light* for a given computer. (Some information in the following table is unknown to the author and is left blank.)

Table 6

Toward Peak Performance

Computer	Actual Performance 1000×1000 MFLOPS	Actual Performance Time sec	Theoretical Peak MFLOPS	Theoretical Peak Cycle time nsec	Theoretical Peak # procs
CRAY Y-MP/832 (8 processor)	2144	.312	2667	6	8
CRAY 2S (4 processors)	1406	.476	1951	4.1	4
CRAY Y-MP/832 (4 processor)	1159	.577	1333	6	4
CRAY 2S (3 processors)	1084	.617	1463	4.1	3
CRAY Y-MP/832 (3 processor)	887	.754	1000	6	3
NEC SX-2	885	.756	1300	6	1
CRAY X-MP/4 (4 processors)	822	.813	941	8.5	4
CRAY 2S (2 processors)	741	.902	976	4.1	2
CRAY X-MP/4 (3 processors)	626	1.07	706	8.5	3
CRAY Y-MP/832 (2 processor)	604	1.11	667	6	2
ETA 10-E (1 processor/half precision)	600	1.12	762	10.5	1
Hitachi S-810/20			840	14	1
Amdahl 1400-E			1714	7	1
Amdahl 1200-E			857	7	1
Amdahl 1400	521	1.28	1142	7	1
IBM 3090/600S VF (6 processors)	518	1.29	798	15	6
Amdahl 1100-E			571	7	1
Amdahl 1200	424	1.57	571	7	1
Fujitsu VP-200	422	1.58	533	7.5	1
NEC SX-1	422	1.56	650	7	1
CRAY X-MP/4 (2 processors)	426	1.57	488	8.5	2
IBM 3090/500S VF (5 processors)	439	1.52	665	15	5
IBM 3090/600E VF (6 processors)	387	1.73	696	17.2	6
CRAY 2S (1 processor)	384	1.74	488	4.1	1
IBM 3090/400S VF (4 processors)	354	1.89	532	15	4

Computer	Actual Performance 1000×1000 MFLOPS	Actual Performance Time sec	Theoretical Peak MFLOPS	Theoretical Peak Cycle time nsec	Theoretical Peak # procs
ETA 10-E (1 processor)	334	2	381	10.5	1
IBM 3090/500E VF (5 processors)	332	2.02	580	17.2	5
ETA 10-Q (1 processor/half precision)	331	2.02	421	19	1
CDC Cyber 205 (4-pipe/half precision)	308	2.16	400	20	1
CRAY Y-MP/832 (1 processor)	308	2.17	333	6	1
IBM 3090/300S VF (3 processors)	272	2.46	399	15	3
IBM 3090/400E VF (4 processors)	270	2.48	464	17.2	4
ETA 10-P (1 processor/half precision)	262	2.55	333	24	1
Amdahl 1100	248	2.69	285	7	1
Amdahl 500-E			285	7	1
NEC SX-1E	221	3.00	325	7	1
CRAY X-MP/4 (1 processor)	218	3.07	244	8.5	1
IBM 3090/300E VF (3 processors)	208	3.21	348	17.2	3
CDC Cyber 205 (2-pipe/half precision)	195	3.41	200	20	1
CDC Cyber 205 (4-pipe)	195	3.42	400	20	1
ETA 10-Q (1 processor)	185	3.63	210	19	1
CRAY X-MP/14se	184	3.63	210	10	1
IBM 3090/200S VF (2 processors)	184	3.64	266	15	2
IBM 3090/280S VF (2 processors)	183	3.65	266	15	2
ETA 10-P (1 processor)	146	4.59	167	24	1
IBM 3090/200E VF (2 processors)	141	4.73	232	17.2	2
IBM 3090/280E VF (2 processors)	139	4.82	232	17.2	2
Amdahl 500	133	5.02	142	7	1
IBM 3090/200 VF (2 processors)	129	5.20	216	18.5	2
CDC Cyber 205 (2-pipe)	113	5.91	200	20	1
CRAY 1S	110	6.07	160	12.5	1
Fujitsu VP-50			133	7.5	1
FPS-164 + 15 MAX	101	6.63			15
IBM 3090/180S VF (1 processor)	92	7.27	133	15	1
CONVEX C-220	84	7.98	100	40	2
NAS AS/XL V60	82	8.15			1
FPS-164 + 8 MAX	79	8.44			8
IBM 3090/180E VF	71	9.36	116	17.2	1
Alliant FX/80 (8 proc)	69.3	9.64	188	85	8
IBM 3090/180 VF	65	10.3	108	18.5	1
IBM 3090/150E VF	64	10.4	112	17.75	1
Alliant FX/80 (7 proc)	63.1	10.6	164.5	85	7
Alliant FX/80 (6 proc)	56.8	11.8	141	85	6
FPS-164/364 + 4 MAX	55	12.1			4
IBM 3090/120E VF	54	12.4	108	18.5	1
Alliant FX/80 (5 proc)	49.1	13.6	117.5	85	5
FPS-164/364 + 3 MAX	47	14.3			3
Alliant FX/80 (4 proc)	41.2	16.2	94	85	4
CONVEX C-210 (1 proc)	44	15	50	40	1
SCS-40 CFT 1.13	40	16.6	44	45	1
CDC Cyber 180-990	40	16.7			1
FPS-164/364 + 2 MAX	36	18.4			2
FPS-264 (M64/60)	34	19.8	38	53	1
Alliant FX/40 (4 proc)	32.6	20.5	47	85	4

Computer	Actual Performance 1000 × 1000 MFLOPS	Actual Performance Time sec	Theoretical Peak MFLOPS	Theoretical Peak Cycle time nsec	Theoretical Peak # procs
Alliant FX/80 (3 proc)	32.3	20.7	70.5	85	3
CONVEX C-130	31	22.4	36	55	1
Alliant FX/8 (8 processors)	29	23.5	94	170	8
Alliant FX/40 (3 proc)	26.8	24.9	35.4	85	3
FPS-164/364 + 1 MAX	24	27.7			1
Alliant FX/80 (2 proc)	22.4	29.8	47	85	2
Alliant FX/4 (4 proc)	20.7	32.3	47	170	4
Alliant FX/40 (2 proc)	19.2	34.8	23.6	85	2
AMT DAP510 (half precision)	19	34.5	100	1024	
Alliant FX/4 (3 proc)	17.3	38.7	35.4	170	3
FPS-264/20 (M64/50)	17	40.0			1
CONVEX C-120	17	40	20	100	1
NAS AS/XL 60	14	48.8			1
Ardent Titan-1 (1 proc)	12	54	16	125	1
Alliant FX/4 (2 proc)	12	55.8	23.6	170	2
Alliant FX/80 (1 proc)	11.6	57.7	23.5	85	1
Alliant FX/40 (1 proc)	10.1	66.1	11.8	85	1
Cydrome Cydra 5			25	80	1
Prime MXCL 5			25	80	1
CONVEX C-1			20	100	1
Intel iPSC d4/VX (16 processors)	11	60.1			16
FPS-164/364 (M64/30)	10	61.3			1
Intel iPSC/2 (64 processors/half precision)	9.72	68.8			
FPS-164/364 (M64/40)	9	71.2			1
MIPS M/2000	6.7	99.9	12.5	40	1
ELXSI 6420 (5 processors)	6.4	104			5
Alliant FX/4 (1 proc)	6.3	106	11.8	170	1
Intel iPSC/2 (32 processors/half precision)	6.26	107			
Alliant FX/1	4.4	153	11.8	170	1
IBM 3081-KX (2 processors)	4.0	166			2
ELXSI 6420 (3 processors)	4.0	167			3
Intel iPSC/2 (16 processors/half precision)	3.66	183			
MIPS M/120	3.6	185	8.3	60	1
ELXSI 6420 (2 processors)	2.7	245			2
Multiflow TRACE/7			15	130	1
Culler PSC			5	200	1
DEC VAX 6240 (4 proc)	2.0	332			
Intel iPSC/2 (8 processors/half precision)	1.99	337			
DEC VAX 6230 (3 proc)	1.5	439			
Sequent Balance 21000 (30 processors)	1.5	445			30
ELXSI 6420 (1 processor)	1.4	475			1
SUN 4/260	1.1	593	3.3		1
Intel iPSC/2 (4 processors/half precision)	1.03	652			
DEC VAX 6220 (2 proc)	1.0	654			
Intel iPSC d5 (32 processors)	.79	843			32
SUN-3/260 + FPA 3.2 f77	.76	874	3.3		1
SUN-3/160 + FPA 3.2 f77	.62	1065	3.3		1
Intel iPSC/2 (2 processors/half precision)	.52	1280			
DEC VAX 6210 (1 proc)	.52	1295			

Computer	Actual Performance 1000×1000 MFLOPS	Performance Time sec	Theoretical Peak MFLOPS	Cycle time nsec	# procs
SUN-3/260, 20 MHz 68881 3.2 f77	.17	4032	.25	50	1
SUN-3/160, 16.7 MHz 68881 3.2 f77	.15	4431		60	1

A Look at Parallel Processing

During the course of collecting the data in Table 6 we have had the opportunity to experiment with parallel processing on a number of computer systems.

The algorithm used was either the standard LINPACK algorithm or one based on matrix-matrix techniques [4]. In the case of the LINPACK algorithm the loop around SAXPY can be performed in parallel. In the matrix-matrix implementation the matrix product can be split into submatrices and performed in parallel. In either case it is a simple fork and join model where each processor get some number of operations to perform.

We consider this algorithm for a problem of this size to be one which has a high degree of parallelism, so it is not suprising that we get such high efficiency. The actual percentage of parallelism depends on the algorithm and on the speed of the uniprocessor on the parallel part relative to the speed of the uniprocessor on the non-parallel part. The ratio of these two speeds can be a quite large, especially if the parallel part is done at peak uniprocessor speed and the non-parallel part is performing less efficient tasks.

Table 7

A Look at Parallel Processing

Computer	1000 x 1000 Problem Using Parallel Processing				
	Time uniprocessor	no. of processors	Time multiprocessors	Speedup	Efficiency
CRAY Y-MP/8	2.17	8	.312	6.96	.87
CRAY Y-MP/8	2.17	4	.577	3.76	.94
CRAY Y-MP/8	2.17	3	.754	2.88	.96
CRAY Y-MP/8	2.17	2	1.11	1.96	.98
CRAY 2S	1.76	4	.476	3.66	.91
CRAY 2S	1.76	3	.617	2.82	.94
CRAY 2S	1.76	2	.902	1.93	.96
CRAY X-MP/4	3.10	4	.813	3.78	.94
CRAY X-MP/4	3.10	3	1.07	2.87	.96
CRAY X-MP/4	3.10	2	1.57	1.96	.98
IBM 3090/600S VF	7.27	6	1.29	5.64	.94
IBM 3090/500S VF	7.27	5	1.52	4.78	.96
IBM 3090/400S VF	7.27	4	1.89	3.85	.96
IBM 3090/300S VF	7.27	3	2.46	2.96	.99
IBM 3090/280S VF	7.27	2	3.65	1.99	.99
IBM 3090/200S VF	7.27	2	3.64	1.99	.99
IBM 3090/600E VF	9.36	6	1.73	5.41	.90
IBM 3090/500E VF	9.36	5	2.02	4.63	.93
IBM 3090/400E VF	9.36	4	2.48	3.77	.94
IBM 3090/300E VF	9.36	3	3.21	2.92	.97
IBM 3090/200E VF	9.36	2	4.73	1.98	.99
CONVEX C-220	15	2	7.98	1.88	.94
Alliant FX/80	57.7	8	9.64	5.99	.75
Alliant FX/80	57.7	7	10.6	5.44	.78
Alliant FX/80	57.7	6	11.8	4.89	.82
Alliant FX/80	57.7	5	13.6	4.24	.85
Alliant FX/80	57.7	4	16.2	3.56	.89
Alliant FX/80	57.7	3	20.7	2.79	.93
Alliant FX/80	57.7	2	29.8	1.94	.97
Alliant FX/40	66.1	4	20.5	3.22	.81
Alliant FX/40	66.1	3	24.9	2.65	.88
Alliant FX/40	66.1	2	34.8	1.90	.95
Alliant FX/4	106	4	32.3	3.28	.82
Alliant FX/4	106	3	38.7	2.74	.91
Alliant FX/4	106	2	55.8	1.90	.95
ELXSI 6420	475	5	104	4.57	.91
ELXSI 6420	475	3	167	2.84	.95
ELXSI 6420	475	2	245	1.94	.97
DEC VAX 6240	1295	4	332	3.90	.98
DEC VAX 6230	1295	3	439	2.95	.98
DEC VAX 6220	1295	2	654	1.98	.99
Sequent Balance 21000	11111.	30	445	25.0	.83

Ground Rules for Running the Benchmarks and How to Receive the Software

The software used to generate the data for this report can be obtained by sending electronic mail to

netlib@anl-mcs.arpa

To receive the single precision software for tables 1-4 labeled "Solving a System of Linear Equations with LINPACK Using All Fortran" in the mail message type:

send linpacks from benchmark

To receive the double precision software for those tables type:

send linpackd from benchmark.

To run the timing programs you will need to supply the function SECOND, which when called reports elapse time.

Ground rules for running this benchmark -

(Tables 1 and 3: Fortran code) No changes are to be made to the Fortran source code—not even changes in the comments.

(Tables 2 and 4: Coded BLAS) Replacements are allowed only in the BLAS (routines DAXPY, DDOT, IDAMAX, DSCAL, or SAXPY, ISAMAX, SSCAL). In all cases, the main driver routines, with it's test matrix generator and residual check must be used.

To receive the single precision software for table 5 labeled "Solving a System of Linear Equations Using the Vector Unrolling Technique" in the mail message type:

send lus from benchmark

To receive the double precision software for that table type:

send lud from benchmark

Ground rules for running this benchmark -

Replacements or modifications are allowed only in subroutines DMXPY and DXMPY (or SMXPY and SXMPY). In all cases, the main driver routines, with it's test matrix generator and residual check must be used.

To receive the single precision software for table 6 labeled "Toward Peak Performance" in the mail message type:

send 1000s from benchmark

To receive the double precision software for that table type:

send 1000d from benchmark

Ground rules for running this benchmark -

Replacements or modifications are allowed in routine LU. The user is allowed to supply any method for the solution of the system of equations. The MFLOP rate, however, will be computed based on the operation count for LU decomposition. In all cases, the main driver routines, with it's test matrix generator and residual check must be used.

To have results verified, please send the output of the runs to

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Acknowledgments

I would like to thank the people who have helped in putting together this collection.

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