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Ronald Schmickley and David H. Bailey

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Now that the hardware and software environment of the Cray-2 is more stable, some comparisons can be made between the performance of the Cray-2 and that of other supercomputers at Ames, notably the Cray X-MP. The comparisons below were made on a suite of thirteen floating-point intensive programs typical of codes expected to run on the NAS High Speed Processor. There are four sets of figures for each program:

- Cray-2 Stand-Alone: The performance of the Cray-2 running on a single CPU with other CPUs idle.
- Cray-2 Simultaneous: The average performance of the four Cray-2 CPUs simultaneously running the same program.
- Cray-2 Normal: The performance of a single CPU with a typical daytime background of jobs running in the other three CPUs.
- Cray X-MP Normal: The performance of the Cray X-MP/12 with a normal amount of swapping with other jobs.

Some of these programs have also been run on the Cray X-MP/48. The run times in each case were very close to the Cray X-MP/12 run times. This is largely due to the fast memory in the Cray X-MP computers, which minimizes the effect of memory bank contention in the four processor model. As a result, the Cray X-MP/12 performance figures can be considered to be highly accurate estimations of the performance of the Cray X-MP/48 on these programs.

The numbers shown in the table below are MFLOPS, computed using a Cray timing routine. The floating-point operation counts were obtained using the hardware performance monitor on the Cray X-MP/12. It is assumed here that the number of floating-point operations performed on the Cray-2 is the same as on the Cray X-MP/12, although there may be small differences.

Most of these codes are actual NASA Ames user codes, although some are not current production versions. Those that are not actual user codes include LLOOPS (the Livermore loops), MATEST (performs the matrix inversion technique developed by Ferguson and one of the authors), NASKERN (the NAS Kernel Benchmark Program with some tuning), and PITEST (a computational computer test program). These tests were run using the most recent versions of the Fortran compilers available on each machine: CFT 2.63 on the Cray-2 and CFT 1.14 BF3 on the Cray X-MP.

The figures in the column headed Ratio are the normal load MFLOPS figures of the Cray-2 divided by the normal load figures of the Cray X-MP/12. These rates are considered

Program Name	Cray-2 Stand-Alone	Cray-2 Simultaneous	Cray-2 Normal	Cray X-MP Normal	Ratio (Percent)
ARC3	42.91	26.98	30.11	51.35	58.64
ATRANS	12.68	10.81	10.43	21.10	49.43
BL3D	44.98	37.65	37.81	51.10	73.98
DERTRA	18.51	15.63	15.78	20.97	75.23
F3D	32.51	24.70	26.46	33.71	78.51
INS3D	54.55	38.93	41.35	52.75	78.39
LES	90.36	53.21	55.34	83.37	66.38
LLOOPS	9.58	9.28	9.01	14.89	60.50
MATEST	394.55	231.01	244.31	192.48	126.93
NASKERN	94.17	53.72	57.28	91.21	62.80
PITEST	165.05	161.16	146.52	131.20	111.68
PNS3D	5.76	5.24	5.04	10.77	46.83
SUNSX	3.99	3.75	3.57	9.56	37.33
AVERAGE					71.28

Table 1: Cray-2 and Cray X-MP Performance (MFLOPS)

to be the most realistic system performance measures. Note, however, that the stand-alone figures for the Cray-2 on several programs, notably ARC3, LES, and MATEST, are considerably higher than the normal results.

Several conclusions may be immediately drawn from the above data. First of all, the MFLOPS performance figures vary dramatically from program to program. This variance depends most strongly on the degree of vectorization. The performance ratio of the two machines also depends highly on the degree of vectorization. The Cray-2 out-performs the X-MP on some highly-vectorized programs, but on scalar codes the slower memory of the Cray-2 results in performance rates sharply lower than the X-MP. The average performance ratio listed in the table above indicates that users should expect about 30% slower performance on the Cray-2 for a program previously running on the Cray X-MP.

Based on these results and some other comparisons, the types of codes that will likely perform well on the Cray-2 compared to the Cray X-MP include the following:

- Library subroutine intensive codes (i.e. those codes that can utilize assembly-coded library subroutines to perform a significant part of their computation).
- Register-intensive codes (i.e. those that perform only a few main memory stores and fetches for a given amount of computation).
- Very small memory codes or other codes that can effectively utilize local memory.

The types of codes that will likely not perform well in comparison to the X-MP include the following:

- Scalar codes (because such codes spend most of their time fetching from and storing to the slow main memory).
- Partially vectorized codes (again because of the scalar disadvantage).
- Main memory intensive codes (i.e. those that perform numerous main memory stores and fetches for a given amount of computation).
- Codes with power-of-two memory strides in major loops.

The slower observed performance of the Cray-2 is mitigated by the following two factors. First of all, CFT 1.14 on the Cray X-MP is significantly more mature than the Cray-2 compiler. Not only is it more reliable, but its vectorization analysis is more advanced, and it has been highly tuned for the X-MP. Secondly, these test codes are mostly Cray X-MP codes written for that machine. Some of these codes are even derivatives of old CDC 7600 codes. Only two of them were written specifically for the Cray-2, and the Cray-2 out-performed the Cray X-MP in these cases.

The two codes MATEST and PITEST were included in this list to demonstrate that the Cray-2 is capable of truly astonishing performance on complete application codes. In each case these codes were written from the ground up specifically to run on the Cray-2. Care was taken to code all major loops in a style that would permit full vectorization with long vector lengths and a minimum of main memory activity. In the case of MATEST, the optimized library subroutine MXM was utilized to multiply matrices, which represents a large part of the computation. As a result, the performance rates of these programs were significantly higher than the others on the list, and in each case the Cray-2 ran the program faster than the Cray X-MP.

Realistically, however, the Cray-2 should be expected to run about 30% slower than the X-MP on most Fortran codes, given the same amount of effort in optimization on each machine. Some improvements in the Cray-2 performance can be expected as the Fortran compiler matures, but it is not likely that many codes will run substantially faster as a result. Some codes will run faster as users increase the array sizes of their codes to take advantage of the larger main memory on the Cray-2. However, other codes already employ reasonably long vector lengths and will not run significantly faster with longer loop lengths.

Utilization of local memory may help in some cases, but none of the CFD codes currently in use seem to be able to make good use of it. The dramatic difference in performance between stand-alone and simultaneous runs in some of the cases above indicates that much of the Cray-2's speed disadvantage may be due to memory bank contention, a problem currently exacerbated by the disabling of pseudo-banking. If this is the case, the performance of the Cray-2 would sharply improve if it could be retrofitted with static RAM chips in mainmemory.

In any event, it should be re-emphasized that the principal advantage of the Cray-2 is its very large memory, which allows jobs that previously could only be run using massive disk or solid state device I/O to now run in main memory. This is a MAJOR advantage, and it should not be allowed to be overshadowed by the slightly slower performance of the Cray-2 on some codes.

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16. Abstract

A suite of thirteen large Fortran benchmark codes were run on Cray-2 and Cray X-MP supercomputers. These codes were a mix of compute-intensive scientific application programs (mostly Computational Fluid Dynamics) and some special vectorized computation exercise programs. For the general class of programs tested on the Cray-2, most of which were not specially tuned for speed, the floating point operation rates varied under a variety of system load configurations from 40% up to 125% of X-MP performance rates. We conclude that the Cray-2, in the original system configuration studied (without "memory pseudo-banking") will run untuned Fortran code, on average, about 70% of X-MP speeds.

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