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# Computer Workstation Speeds

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MASTER

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# Computer Workstation Speeds

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## Abstract

This report compares the performance of several computers. The speeds of running three numerically intensive programs are reported for each computer. These speeds are correlated with industry-standard performance ratings.

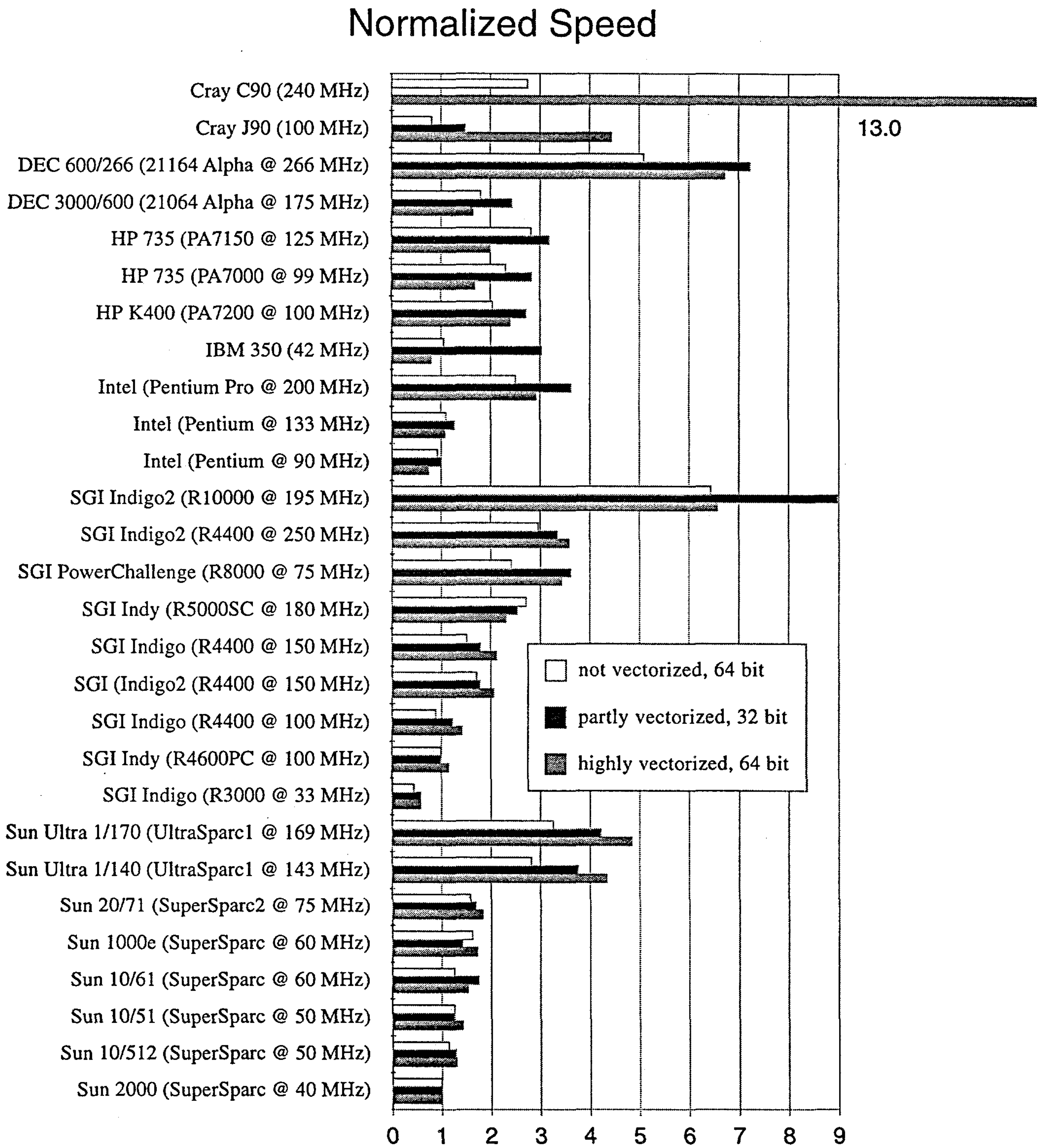


**Figure 1.** *Speeds of running the three benchmark programs (longer is better). Speed is the reciprocal of running time. For each program, the speeds have been normalized so a Sun 2000 (SuperSparc @ 40 MHz) has speed 1.*

## Introduction

This report compares the performance of several computers. Some of the machines are discontinued, and some are anticipated, but most are currently installed at Sandia Laboratories. All the computers are personal workstations or departmental servers, except for comparison, one is a Cray C90 mainframe supercomputer (not owned by the Laboratories). A few of the computers have multiple processors, but parallelism is not tested.

The time to run three programs is reported for every computer. Unlike many benchmarks, these are complete application programs. They were written and are used at Sandia Laboratories.

Also SPECmarks are reported for many computers. These are industry standard performance ratings. They are in general agreement with the speeds of running the Sandia programs.

This report concludes with some background material and notes about specific manufacturers.

## Benchmark Programs

The three benchmark programs primarily test calculating speed. **Table 1** describes the programs: the first is a heat transfer calculation, the second two are reacting fluid flow calculations. All the programs are configured to use fairly little memory, so paging is not required on any computer. The programs are written in Fortran 77. They are probably typical of procedural, numerical software that does little input and output. The programs are probably not typical of other software.

**Table 1.** *The Sandia programs used in the benchmarks.*

| extent of vectorization | arithmetic precision | program name |
|---|---|---|
| not vectorized | 64 bit | twafer [12] |
| partly vectorized | 32 bit | current [15] |
| highly vectorized | 64 bit | ovend [11] |

**Figure 1** displays the programs' speeds on many computers. Speed is the reciprocal of running time. For each program, the speeds have been normalized so an older Sun server has time 1. The Appendix lists the timing data from which the Figure is derived.

The fastest computers *among those tested* are the Cray C90 mainframe supercomputer, followed by in order the fastest from SGI, DEC, SUN, Intel and HP. The tested computers may not be the fastest currently available from their manufacturers, see below.

## SPEC Ratings

Twenty-four computer makers sponsor a nonprofit group, the Standard Performance Evaluation Corporation (SPEC) [6], that maintains several rating systems for computer speed. These "SPECmarks" are based on running times of several programs.

The most popular SPECmarks are SPECint92 and SPECfp92, which measure optimized integer and real arithmetic speed, respectively. Speed is relative to a VAX 11/780, whose ratings are 1. The Appendix lists these SPEC92 ratings for many computers.

The SPEC92 ratings generally agree with the speeds measured for the Sandia programs. Correlation coefficients are commonly used to measure agreement between pairs of data sequences. **Table 2** lists the six correlation coefficients for the two sequences of SPEC92 ratings paired with the three sequences of speeds for the Sandia programs. A correlation coefficient near 1 indicates strong agreement between the members of the pair.

**Table 2.** *Correlation coefficients between the SPEC92 ratings of the tested computers and the speeds of running the Sandia programs.*

| | SPECint92 | SPECfp92 |
|---|---|---|
| not vectorized, 64 bit, twafer [12] | 0.79 | 0.92 |
| partly vectorized, 32 bit, current [15] | 0.74 | 0.91 |
| highly vectorized, 64 bit, ovend [11] | 0.79 | 0.91 |

Nevertheless, SPECmarks imperfectly indicate actual performance. **Figure 2** compares the SPECfp92 ratings with the normalized speeds of running the highly vectorized Sandia program. This pair of data sequences has a 0.91 correlation coefficient, yet some computers with the same SPECmark have speeds that vary by a factor of two.

Figure 2 thus demonstrates the need for independent testing. "Many industry experts now tend to reject [standardized] tests because it is relatively easy to skew results by compiler tuning" [14]. The SPEC92 ratings are thought to be particularly unreliable, and are being replaced by '95 versions.

## Other Computers

Many fast computers were not tested, and many computers that will become available in 1996 could not be tested. Their performance on the Sandia programs can be extrapolated from similar machines using processor Hertz and SPECmarks. Unfortunately, comparison between old and new computers is difficult because older computers have SPEC92 ratings while newer computers have '95 values.

**Table 3** shows SPEC95 ratings that have been measured for some Intel [5] and SGI [4] computers, or have been estimated for systems built around some anticipated chips [3]. The table's SPEC95 ratings are relative to a Sun 10/40 (SuperSparc @ 40 MHz), which approximates Figure 1's normalization. Reconciling the two sets of data (the SPEC95 ratings and the speeds of running the Sandia programs) for the Intel and SGI computers suggests, very roughly, that SPEC95 ratings should be scaled by 0.5 to approximate the speeds measured for the Sandia programs. This places Table 3's fastest computers between 6 and 10 on Figure 1's scale.

## General Background

Personal workstations are nearly as fast as mainframe supercomputers because much of a computer now fits on a single chip. This inexpensively eliminates the delays of transmitting high frequency signals through wires and across circuit boards. Given this degree of miniaturization, the primary determinants of speed are then (1) clock speed, (2) computer architecture, (3) memory access and (4) word length.

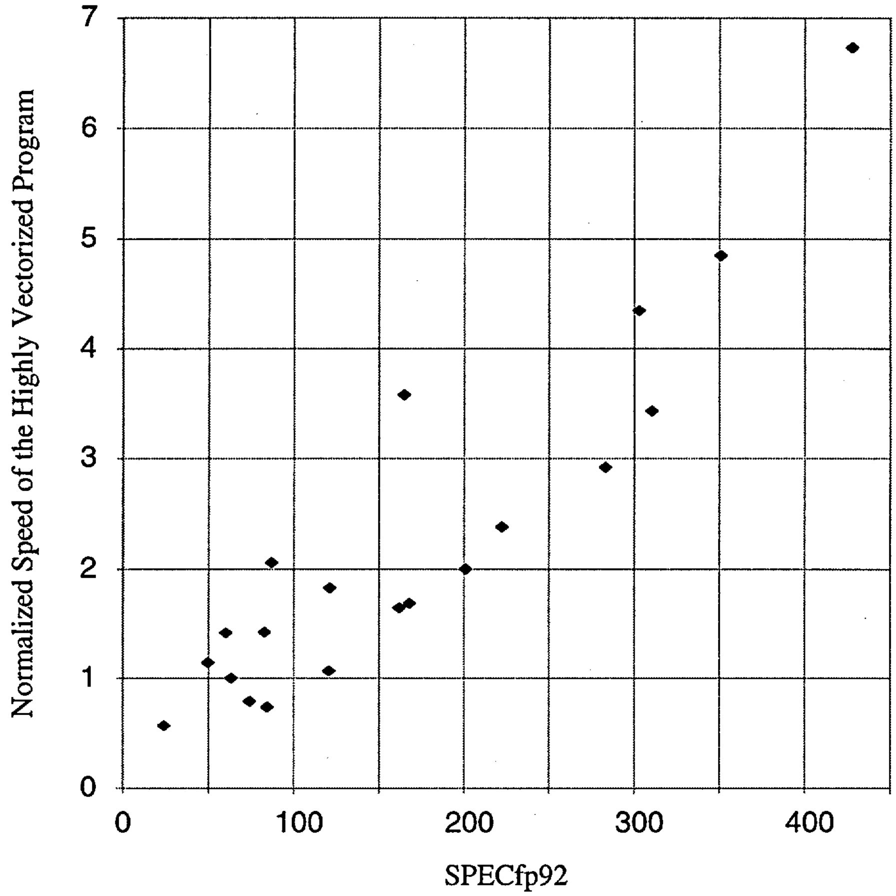


**Figure 2.** *Normalized speeds of running the highly vectorized benchmark, [11], on computers with various SPECfp92 ratings. The speeds have been normalized so a Sun 2000 (SuperSparc @ 40 MHz) has speed 1.*

**Table 3.** *SPEC95 ratings that have been estimated for some anticipated computers [3], or have been measured for some Intel [5] and SGI [4] products.*

| | SPECint95 | SPECfp95 |
|---|---|---|
| HP (PA8000 @ 180 MHz) | 11.8 | 20.2 |
| Sun (UltraSparc2 @ 300 MHz) | 8.5–11.0 | 15.0–18.0 |
| DEC (Alpha @ 400 MHz) | 11.0 | 14.0 |
| SGI (R10000 @ 200 MHz) | 8.9 | 12.3 |
| Intel (Pentium Pro @ 200 MHz) | 8.1 | 6.7 |
| SGI Indy (R5000 @ 180 MHz) | 4.1 | 4.4 |
| Intel (Pentium @ 133 MHz) | 4.1 | 3.1 |

(1) Clock speeds depend largely on manufacturing precision. Some fraction of chips are always exceptionally fast, but advanced fabrication technology [13] is needed to produce fast chips at marketable quantities and costs.

(2) New processor chips exploit fine-grain parallelism. They automatically detect overlapping operations (called superscalar) in programs limited to a small vocabulary of instructions (called risc). The advantage of superscalar technology is that it speeds up all software independent of vectorization. Future chips may rely more on compilers to detect overlapping operations (long instruction word architectures).

(3) Because computers have more memory chips than processor chips, the memory chips are necessarily cheaper and therefore slower. Up to three levels of intermediate-speed memory (called cache) may be used to isolate a fast processor from its slow memory. Unfortunately, the effectiveness of this memory hierarchy varies with the program.

(4) Word length affects speed because numerical software customarily uses 64 bit numbers while many computers have 32 bit bottlenecks in the movement of data.* The only completely 64 bit chips seem to be those from DEC (all chips), HP (the PA7200 and later), SGI (all), and Sun (UltraSparc and later). To remain compatible with older software, even computers built from these chips may not fully use their 64 bit capabilities. The only completely 64 bit operating systems seem to be those from DEC (all versions) and SGI (version 6.0 and later).

## Specific Manufacturers

**Apple:** Data for Apple computers is missing due to lack of patience with compiler interfaces other than that of unix. Apple seems not to provide SPECmarks for its computers, but there are ratings for PowerPC chips in other systems [7].

**Cray:** The T90 (not tested) has a clock speed of 500 MHz so it should be twice faster than the C90. These mainframe supercomputers are much more expensive than the J90 departmental server.

**DEC:** There are 333 and 400 MHz versions of the 266 MHz chip tested here.

**HP:** HP and Intel have announced they will jointly develop and manufacture chips. A long instruction word processor (which is not the P7 mentioned below) is said to be a goal of this collaboration.

**IBM:** The model 350 is an older product that probably is not representative of IBM workstations today.

**Intel:** The 200 MHz Pentium Pro will be used in the Intel-Sandia teraflop computer. The Pentium Pro is expected to reach 333 MHz [8]. The Pentium, the Pentium Pro and the forthcoming P7 are 16, 32 and 64 bit chips, respectively.

**Motorola:** The anticipated PowerPC 620 chip is said to be twice faster than the current Pentium Pro [9].

**SGI:** The R10000 chip is expected to be available at faster speeds than the 195 MHz version tested here.

**SUN:** The 143 and 169 MHz UltraSparc1 chips tested here are also available in a 200 MHz version.

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* These bottlenecks do not affect floating point arithmetic precision. Any chip that conforms to the IEEE arithmetic standard, as most do, can be expected to use 32 bit numbers for Fortran 77 single precision and C float data types, and 64 bit numbers for Fortran double precision and C double data types.

## Appendix

This Appendix lists the unnormalized benchmark data and the SPEC92 ratings from which Figures 1 and 2 are derived. SPECmarks are available from SPEC [6], a variety of third parties such as [7] and [10], and from manufacturers such as [1] [2], [4] and [5].

For the Sandia programs, recall (a) is not vectorized with 64 bit precision [12], (b) is partly vectorized 32 bit [15], and (c) is highly vectorized 64 bit [11]. All the programs run with 64 bit precision on the Crays.

Running time is the "user" time reported by the unix "time" function. The partly vectorized benchmark, (b), performs a sequence of identical steps, so time per step is reported for this program.

Some effort is made to compile the benchmarks using high levels of optimization. The very highest levels generally are difficult to apply to large programs and do not always improve performance. A few subroutines in the benchmarks require low optimization to avoid run-time errors on some computers.

| | time (seconds) | | | SPEC92 | |
|---|---|---|---|---|---|
| | (a) | (b) | (c) | int | fp |
| Cray C90 (240 MHz) | 11.50 | | 14.15 | | |
| Cray J90 (100 MHz) | 39.02 | 1.73 | 41.33 | | |
| DEC 600/266 (Alpha 21164 @ 266 MHz) | 6.20 | .36 | 27.30 | 288.0 | 428.0 |
| DEC 3000/600 (Alpha 21064 @ 175 MHz) | 17.60 | 1.06 | 111.70 | 114.1 | 162.1 |
| HP K400 (PA7200 @ 100 MHz) | 15.50 | .95 | 77.10 | 135.0 | 221.0 |
| HP 735 (PA7150 @ 125 MHz) | 11.20 | .81 | 91.90 | 136.0 | 201.0 |
| HP 735 (PA7100 @ 99 MHz) | 13.70 | .91 | 108.80 | 109.1 | 167.9 |
| IBM 350 (42 MHz) | 30.00 | .85 | 230.60 | 35.4 | 74.2 |
| Intel (Pentium Pro @ 200 MHz) | 12.62 | .71 | 62.93 | 318.4 | 283.2 |
| Intel (Pentium @ 133 MHz) | 28.75 | 2.05 | 171.59 | 174.2 | 120.6 |
| Intel (Pentium @ 90 MHz) | 34.18 | 2.56 | 246.92 | 110.1 | 84.4 |
| SGI Indigo2 (R10000 @ 195 MHz) | 4.91 | .29 | 27.97 | | |
| SGI Indigo2 (R4400 @ 250 MHz) | 10.68 | .77 | 51.34 | 176.0 | 165.0 |
| SGI PowerChallenge (R8000 @ 75 MHz) | 13.08 | .71 | 53.54 | 108.7 | 310.6 |
| SGI Indy (R5000SC @ 180 MHz) | 11.64 | 1.01 | 79.66 | 62.8 | 49.9 |
| SGI Indigo (R4400 @ 150 MHz) | 20.76 | 1.44 | 86.69 | | |
| SGI Indigo2 (R4400 @ 150 MHz) | 18.46 | 1.45 | 89.34 | 90.0 | 87.0 |
| SGI Indigo (R4000 @ 100 MHz) | 35.98 | 2.10 | 129.76 | 57.6 | 60.3 |
| SGI Indy (R4600PC @ 100 MHz) | 31.57 | 2.60 | 160.46 | 62.8 | 49.9 |
| SGI Indigo (R3000 @ 33 MHz) | 72.39 | 4.46 | 320.21 | 22.4 | 24.2 |

continued next page

| | time (seconds) | | | SPEC92 | |
|---|---|---|---|---|---|
| | (a) | (b) | (c) | int | fp |
| Sun Ultra 1/170 (UltraSparc1 @ 169 MHz) | 9.70 | .61 | 37.90 | 252.0 | 351.0 |
| Sun Ultra 1/140 (UltraSparc1 @ 143 MHz) | 11.20 | .69 | 42.30 | 215.0 | 303.0 |
| Sun 20/71 (SuperSparc2 @ 75 MHz) | 19.90 | 1.53 | 100.40 | 125.8 | 121.2 |
| Sun 1000e (SuperSparc @ 60 MHz) | 19.50 | 1.81 | 106.60 | | |
| Sun 10/61 (SuperSparc @ 60 MHz) | 25.10 | 1.48 | 120.50 | | |
| Sun 10/512 (SuperSparc @ 50 MHz) | 27.90 | 2.02 | 142.10 | | |
| Sun 10/51 (SuperSparc @ 50 MHz) | 25.00 | 2.05 | 129.20 | 65.2 | 83.0 |
| Sun 2000 (SuperSparc @ 40 MHz) | 31.60 | 2.57 | 183.70 | 53.2 | 63.4 |

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