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# EGS4 Benchmark Program

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*Abstract*

This paper proposes EGS4 Benchmark Suite which consists of three programs called UCSAMPL4, UCSAMPL4I and XYZDOS. This paper also evaluates optimization methods of recent RISC/UNIX systems, such as IBM, HP, DEC, Hitachi and Fujitsu, for the benchmark suite. When particular compiler option and math library were included in the evaluation process, system performed significantly better. Observed performance of some of the RISC/UNIX systems were beyond some so-called Mainframes of IBM, Hitachi or Fujitsu. The computer performance of EGS4 Code System on an HP9000/735 (99MHz) was defined to be the unit of EGS4 Unit. The EGS4 Benchmark Suite also run on various PCs such as Pentiums, i486 and DEC alpha and so forth. The performance of recent fast PCs reaches that of recent RISC/UNIX systems. The benchmark programs have been evaluated with correlation of industry benchmark programs, namely, SPECmark.

## I. INTRODUCTION

We pointed out that SPECmark and High Energy Physics benchmark programs such as CERN Benchmark Suite & SSC Benchmark Suite could not be a good evaluation standard for a computer performance of the EGS4 Code System[1,2]. Therefore, we propose to use the EGS4 Benchmark Suite we developed. UCSAMPL4 program is one in the suite. The program is included in the distribution kit of the EGS4 Code System. An incident particle is an electron of 1 GeV energy and the particle penetrates into an iron wall of 3 cm thickness. UCSAMPL4I program has the same incident particle as in the UCSAMPL4, but the penetrated material is an infinitely thick iron. This means all the incident energy will be deposited in the iron. The program was developed by us. The XYZDOS program was developed by A.F.Bielajew at NRCC[3]. The incident particle is an electron that has 20 MeV energy and the medium is water in a form of a 19 cm cube. The "BENCHE" program in the XYZDOS has run. The history numbers of UCSAMPL4, UCSAMPL4I and XYZDOS are 10000, 10000 and 100000, respectively.

The sizes of instruction codes in the three programs are approximately a few hundred KB, but the data sizes are not the same. The data size of UCSAMPL4 and UCSAMP4I are several hundred KB, but that of XYZDOS is over 1 MB. We analyzed the benchmark programs by using analysis tools of "prof" and/or "pixie" and found that there was no hot spot in the benchmark program codes. Hot spot means a local section of program codes that consumes significant portion of CPU time. Execution time for arithmetic functions such as "SQRT" and "LOG" occupied approximately 10 % of the total execution time, but the ratio of the occupancy depended on which CPU architecture and which Operating System with FORTRAN compiler were selected.

We have evaluated a correlation between the incident energy and the execution time of the benchmark programs in Fig. 1. The energy was varied between 200 MeV and 8 GeV. The execution time of UCSAMPL4 was not linear to the incident energy, but that of UCSAMPL4I was linear to the incident energy. On UCSAMPL4I, all the incident energy was deposited into the medium, but all the energy on UCSAMPL4 was not. This means that the execution time of EGS4 Code System is linear to the incident energy if the ratio of the energy deposition and the total energy is kept constant.

CPU time is a measure of computer performance and we will measure this CPU time for EGS4 Code System here. The CPU time is different from an "elapsed time". The elapsed time depends on the other workload because multiple processes on single CPU with a time-sharing operation share the CPU time. The used system function for measuring the CPU time is either "times" function in library of C Language or "etime" function in library of FORTRAN Language. Those functions are usually used for measuring CPU time.

When the benchmark program run several times on a computer, the measured CPU time varied. Fig. 2 shows the distribution of the execution time of UCSAMPL4. The fluctuation reaches up to 10 % of the average execution time. We think that the fluctuation was due to other workload with I/O. The CPU time should not depend on other workload, but we have no way to measure the CPU time without those system functions. Therefore, we have carefully measured CPU time with as low workload as possible to minimize the fluctuation on the measurement. The "execution time" used in the followings is equivalent to the CPU time.

## II. OPTIMIZATION METHOD ON RISC/UNIX SYSTEMS FOR EGS4 CODE SYSTEM

In order to improve the performance of the systems, we decided not to modify the source code of the benchmark program because there was no hot spot and many modifications of the code might change physics results. Instead, we chose the best compiler option of FORTRAN and selected math library. The specifications of computers used for the evaluation are listed in Table 1.

First, we discuss the results from two IBM computers (model 590 and 390). Both CPUs had identical POWER2 architecture, but the cache size and the memory bandwidth were different. The results are shown in Fig. 3. Both computers have almost the same execution time on the benchmark programs. We should investigate the reason why both computers had the same performance with the EGS4 benchmark program although the model 590 had larger size of the cache and higher memory bandwidth than the model 390 (CERN SP). The compiler option "Opt6" in the Fig. 3 is listed in Table 2. The math library of IBM Austin Lab. was effective in shortening the execution time.

The results from HP computers are shown in Fig. 4. Latest HP model J210 computer and the fastest version of HP model 735 were used for the evaluation. In the figures, the model J210 and the model 735 were named as PA7200-120 and PA7150-125 respectively. The execution time with compiler option "Opt5" was the best. The option requires two execution cycles of the program to run beforehand. This means that the first execution of the EGS4 benchmark program makes the profile of the execution. Then, the second compilation makes best optimization code by using the execution profile. This option makes best performance, but the compiler option in Table 2 were used instead for the evaluation. It is because the compiler option in the Table 2 is more likely to be used and is almost as fast.

DEC computers used in this test were AlphaSever 8400 5/300 and AlphaStation 200/233. The Server has the best performance in all of the computers evaluated with the EGS4 benchmark programs. Fig. 5 shows the results. The compiler option "Opt0" means the option "-O0" and the "Opt1" means the default optimization " -O", which corresponds to "-O4". The best options are listed in Table 2. The option "-non_shared" was effective and "-math_library fast" flag was useful in some cases. In case of the XYZDOS, the "math_library fast" flag made the physics result change.

A Hitachi workstation 3500/540 is similar to an HP workstation because both uses the same PA-RISCs for its CPU. But, the performance are not the same because the memory/bus architecture and the Operating System/ FORTRAN compiler are different. The default optimization "O3" flag was effective in executing the UCSAMPL4 and the XYZDOS programs while the best optimization flag "s" is effective on the UCSAMPL4I. Fig. 6 shows results on the Hitachi workstation. The default optimization yields excellent performance.

A Fujitsu workstation had SuperSPARC(60 MHz). Fig. 7 shows the results from the Fujitsu workstation. The four types of the optimizations were always effective on the benchmark programs. The compiler option for the best performance is listed in Table 2.

## III. EGS4 Unit

We have chosen the HP9000/735(99MHz) as the standard computer for evaluating EGS4 benchmark programs. The geometry used with the UCSAMPL4I is very simple while that with the XYZDOS is complicated. These programs represent typical programs of an EGS4 Code System. The execution times of the UCSAMPL4I and of the XYZDOS were measured. The UCSAMPL4I and the XYZDOS took 30.1 sec and 301 sec respectively. The geometric mean of both execution times was used as a normalization value. In contrast to an arithmetic mean, the geometric mean is consistent regardless of the computer used for the reference. Defining the EGS4 Unit of HP9000/735 (99MHz) to be 1, a computer with larger value of the EGS4 Unit will have better performance. Fig. 8 shows the EGS4 Unit of all computers evaluated (including PCs). The EGS4 Unit does not include the evaluation of the UCSAMPL4. It is convenient for a user of the EGS4 Code System to know the correlation between a EGS4 Unit and corresponding execution time of the UCSAMPL4 since the program is included in an EGS4 distribution kit and the execution did not take much time. We defined UCSAMPL4 ratio as a value normalized by the execution time of the program on the standard computer, HP9000/735 (99MHz). The UCSAMPL4 took 15.1 sec. Fig. 9 shows the UCSAMPL4 ratio for all computers tested. The results show that UCSAMPL4 ratio is close but not the same as EGS4 Unit. The performance of a Pentium CPUs is less than that of the RISC/UNIX systems, but that of the fastest Pentium PC reaches 0.8 EGS4 Unit. The Windows/NT on DEC 200 4/233 had the same performance of the OSF/1, reaching 1.6 EGS4 unit. Fig. 10 shows clock dependency of the EGS4 Unit on Pentium CPUs. The result shows that the performance does not increase proportionally to the clock frequency and it depends on cache size and memory architecture. When the clock is over 100 MHz, the clock ratio for a Pentium ( a EGS4 Unit times inverse of the clock frequency of a Pentium at particular frequency divided by the same at 60MHz ) decreases. The 133MHz Pentium (Delta) has a synchronized SRAM cache while Cygnus has an asynchronized SRAM cache. In addition, the Cygnus has high speed DRAM called EDO while Delta does not have. However, Delta has higher performance over Cygnus even if both have the same clock frequency for the CPU. Fig. 11 shows cache dependency of EGS4 Unit on a Pentium CPU. The result shows that the L1 cache improves the performance.

## IV. Correlation between the EGS4 Unit and SPECint92 & SPECfp92

Figs. 12 and 13 show the correlation. In EGS4 Unit versus SPECfp92 graph, SPARC20 and IBM590 have almost the same EGS4 Unit although they have different SPECfp92 values. This means that the SPECfp92 is not adequate for indexing of EGS4 Code System. Figs. 14 and 15 plot SPECint92 ratio and SPECfp92 ratio, respectively. The SPECint92 ratio of the standard computer is set to 1. Where the EGS4 Unit times SPECint92 value of an evaluated computer divided by that of the standard computer is the SPECint92 ratio. The SPECfp92 of an evaluated computer was also calculated in the same fashion. The result shows that SPECint92 is a better index than SPECfp92.

## V. CONCLUSION

The EGS4 Benchmark Suite is appropriate to evaluate the computer performance for EGS4 Code System and hence EGS4 Unit became an index when one compares computer performances.

The optimization method of recent RISC/UNIX systems for the benchmark programs was evaluated. The best compiler option and an addition of particular math library made their performance higher.

The benchmark programs run on various PCs. The EGS4 Units of Pentium PCs was not very high, but the Pentium PCs may have better cost performance.

The correlation between the EGS4 Unit and SPECint92 & SPECfp92 was investigated. The SPECfp92 was found to be inadequate for the indexing.

We are planning to distribute the EGS4 Benchmark Suite.

We will investigate the correlation between a EGS4 Unit and a new benchmark suite, SPEC95.

## VI. ACKNOWLEDGMENT

We would like to thank High Performance Computing group of IBM at Kawasaki, HP Marketing group at Fuchu, System Engineers at DEC Ogikubo and at Tsukuba, System Engineer of Hitachi at KEK and System Engineer of Fujitsu at KEK for their help to run EGS4 benchmark programs. We appreciate Prof. Sverre Jarp of CERN, Dr. Atsushi Manabe and Dr. Takashi Sasaki of KEK for their help during our EGS4 benchmark project. We are grateful to the staff of KEK on-line group and KEK computing center for their support.

## VII. REFERENCE

[1] Y.Yasu et al., High Energy Physics (HEP) Benchmark Program, Proceedings of the Third EGS4 User's Meeting in Japan, KEK Proceedings 93-15(1993), pp.83-104.

[2] Walter R. Nelson, Hideo Hirayama and David W.O. Rogers : THE EGS4 CODE SYSTEM, SLAC-Report-265, (1985)

[3] A.F. Bielajew and D.W.O. Rogers, "A standard timing benchmark for EGS4 Monte Carlo Calculations", Medical Physics 19 303-304(1992).

## Table 1 Specification of evaluated computers

| Computer Model | CPU | Clock (MHz) | Cache | OS | FORTRAN |
|---|---|---|---|---|---|
| HP 9000 Model 735(Std.) | PA7100 | 99 | 256KB(I) 256KB(D) | HP-UX 9.01 | V9.0 |
| IBM Powerstation Model 590 | POWER2 | 67 | 32KB(I) 256KB(D) | AIX V3.2.5 | V3.2.2.1 |
| Model 390 (CERN SP) | POWER2 | 67 | 32KB(I) 64KB(D) | AIX V3.2 | V3.2.0.1 |
| HP 9000 Model J210 | PA7200 | 120 | 256KB(I) 256KB(D) | HP-UX 10.01 ( Pre-release ) | V10.01 ( Pre-release ) |
| Model 735 | PA7150 | 125 | 256KB(I) 256KB(D) | HP-UX 9.05 | V9.05 |
| DEC AlphaServer Model 8400 5/300 | DECchip 21164 | 300 | L1 8KB(I) L1 8KB(D) L2 96KB L3 4MB | OSF1 V3.2B | V3.8 |
| DEC AlphaStation Model 200 | 20164A | 233 | L1 16KB(I) L1 16KB(D) L2 512KB | OSF1 V3.2A | V3.7 |
| HITACHI 3500 Model 540 | PA7100 | 100 | 256KB(I) 256KB(D) | HI-UX05-00 | 0107 |
| FUJITSU S-4/20 Model 61 | Super-SPARC | 60 | L1 36KB L2 1MB | SunOS V5.4 (Solaris 2.4) | Sun Fortran 2.0.1 |

## Table 2 Compiler Option for evaluated RISC/UNIX computers

| | UCSAMPL4 | UCSAMPL4I | XYZDOS |
|---|---|---|---|
| HP735-99(Std.) | +O3 -K -Wl,-aarchive | +O3 -K -Wl,-aarchive | +O3 -K -Wl,-aarchive |
| IBM Model 590 | -O3 -qarch=pwr2 -lmass | -O3 -qarch=pwr2 -lmass | -O3 -qarch=pwr2 -lmass |
| IBM Model 390 | -O3 -qarch=pwr2 -lmass | -O3 -qarch=pwr2 -lmass | -O3 -qarch=pwr2 -lmass |
| HP PA7150-125 | +O4 -K -Wl,-aarchive | +O4 -K -Wl,-aarchive | +O2 -K -Wl,-aarchive |
| HP PA7200-120 | +O4 -K -Wl,-aarchive | +O4 -K -Wl,-aarchive | +O2 -K -Wl,-aarchive |
| DEC 8400 5/300 | -tune ev5 -O5 -math_library fast -non_shared | -tune ev5 -O5 -math_library fast -non_shared | -tune ev5 -vms -O4 -non_shared |
| DEC 200 4/233 | -O5 -math_library fast -non_shared | -O5 -math_library fast -non_shared | -tune ev4 -vms -O4 -non_shared |
| Hitachi 3500/540 | -W0,'opt(o(3))' | -W0,'opt(o(s))' | -W0,'opt(o(3))' |
| Fujitsu SPARC 20-60 | -fast -O4 -Bstatic | -fast -O4 -Bstatic | -fast -O4 -Bstatic |

Table 3. Specification of evaluated PCs

| PC model | CPU | Clock (MHz) | Cache (L2) | Memory | OS | FORTRAN |
|---|---|---|---|---|---|---|
| NEC PC9821Ap2 | i486 | 66 | 128KB | standard | MS-DOS6.2 | Lahey90* |
| DELL Optiplex XM 590 | Pentium | 90 | 256KB | standard | MS-DOS6.2 | Lahey90* |
| DELL Optiplex XM 5100 | Pentium | 100 | 256KB | standard | MS-DOS6.2 | Lahey90* |
| DELL Optiplex XMT 5120 | Pentium | 120 | 256KB | standard | MS-DOS6.2 | Lahey90* |
| PROSIDE (Cygnus) | Pentium | 133 | 256KB | EDO** | WNT3.5 | Watcom*** |
| PROSIDE (Delta) | Pentium | 133 | 256KB (Sync****) | standard | WNT3.5 | Watcom*** |
| DEC Alpha-station Model 200 | DECchip 20164A | 233 | 512KB | standard | WNT3.5 | DEC V1.1-670 |

| | | |
|---|---|---|
| * | Lahey90 : | Revision A, FORTRAN 90 |
| ** | EDO : | Extended Data Out |
| *** | Watcom : | FORTRAN 77 |
| **** | Sync : | Synchronized SRAM cache. Otherwise, Asynchronized SRAM cache |

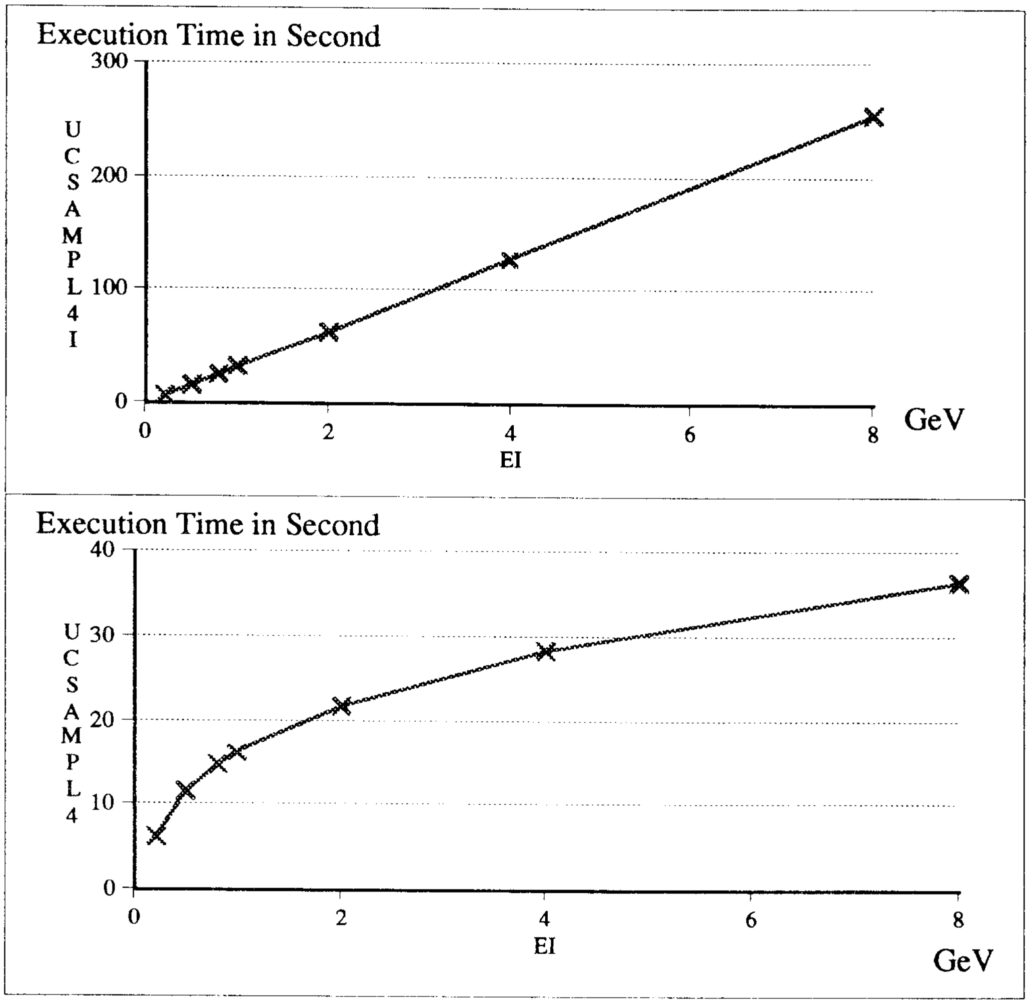


Fig.1 Correlation of EGS4 Execution Time and Incident Energy

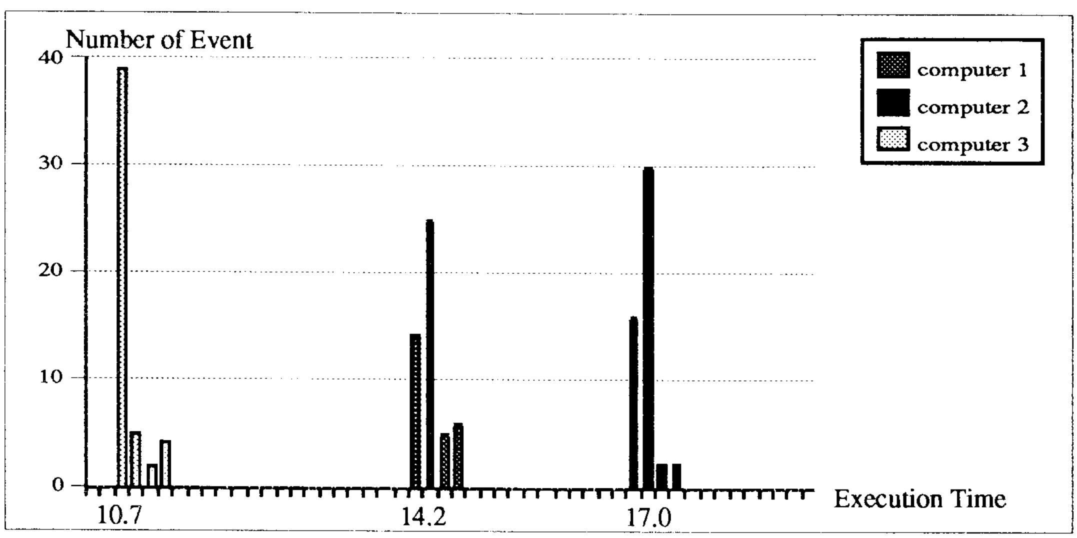


Fig. 2 Fluctuation of Execution Time by Workload

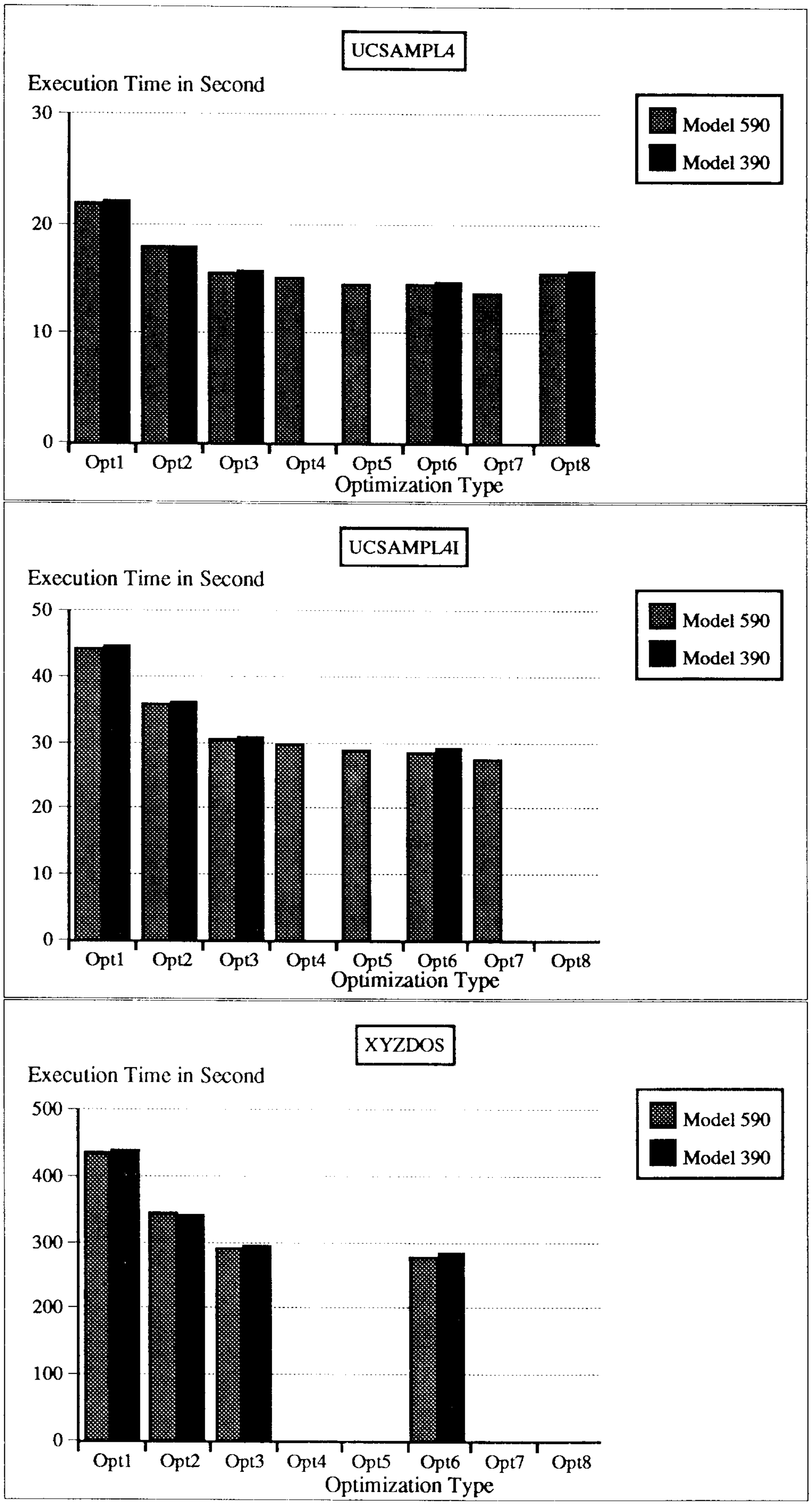


Fig. 3 EGS4 Benchmark Results on IBM Computers

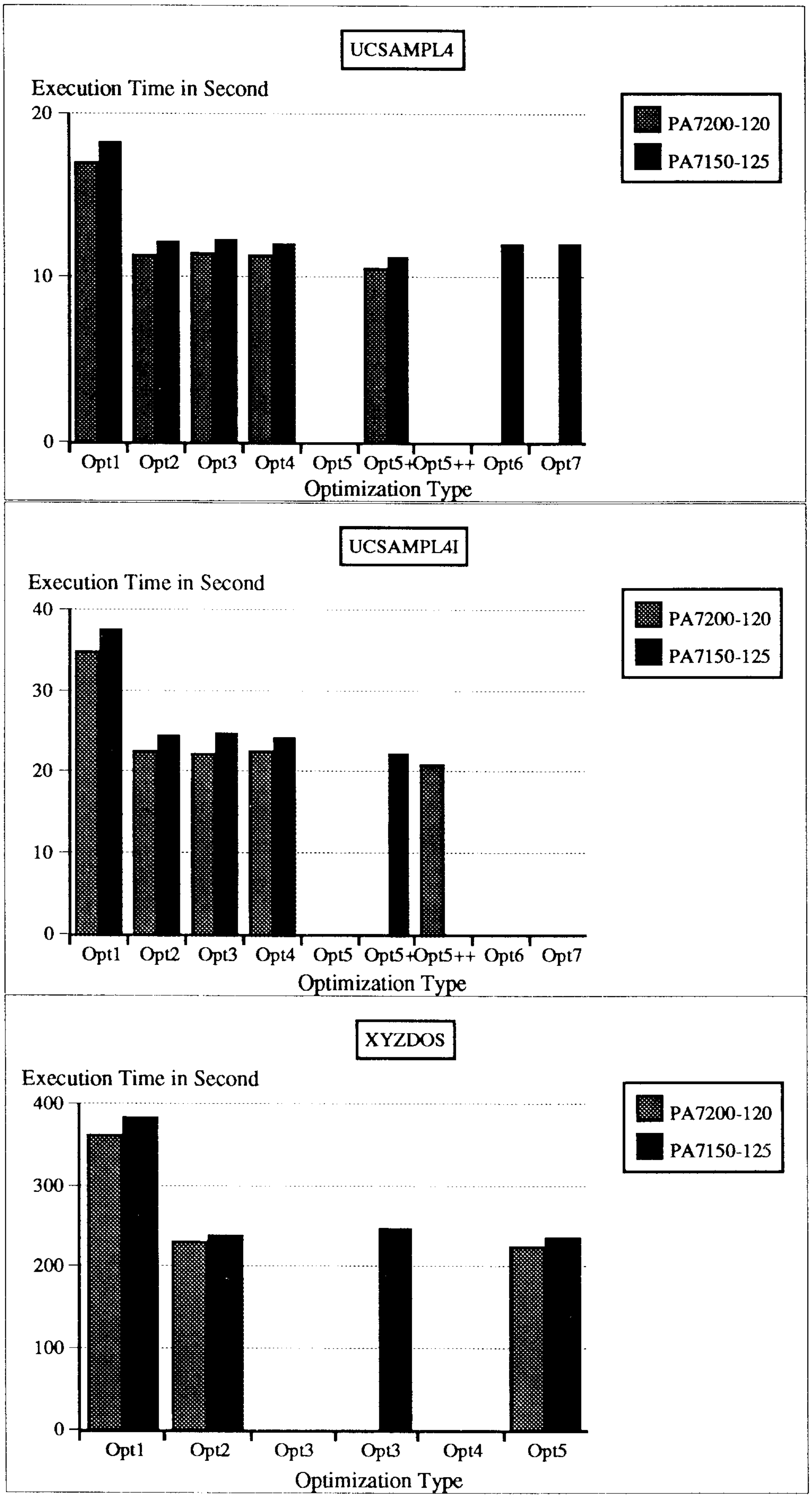


Fig. 4 EGS4 Benchmark Results on HP Computers

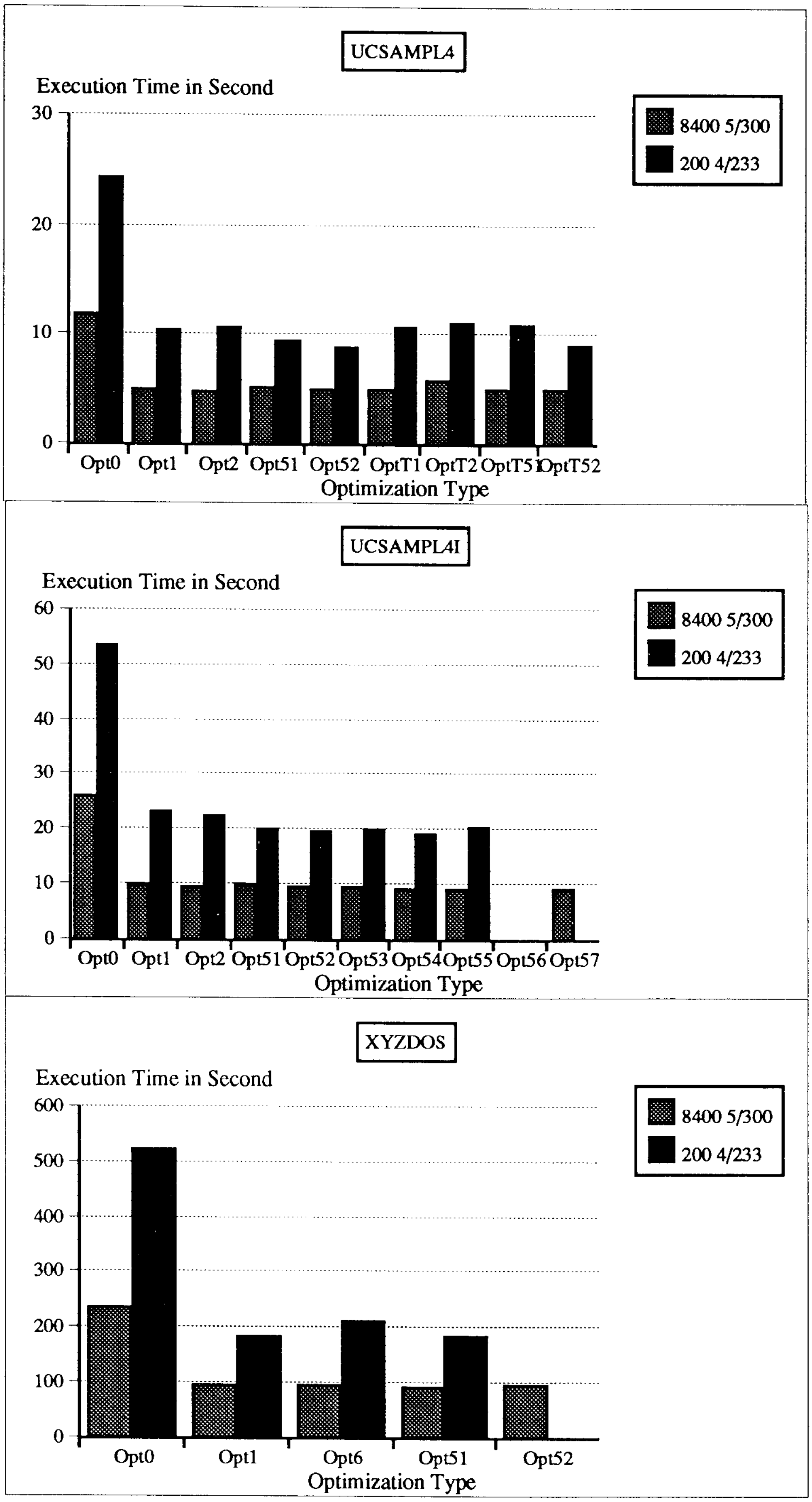


Fig. 5 EGS4 Benchmark Results on DEC Computers

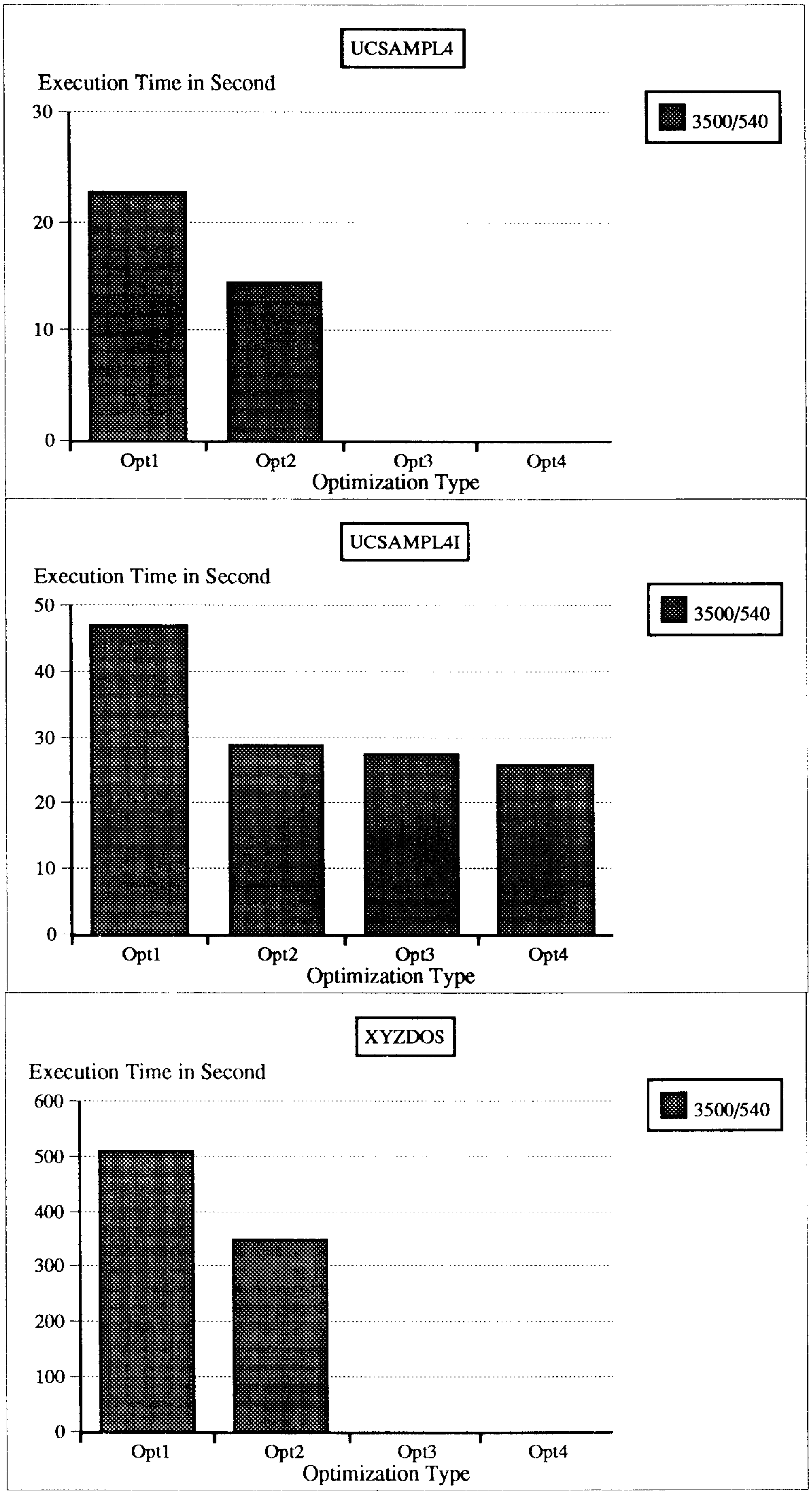


Fig. 6 EGS4 Benchmark Results on Hitachi Computer

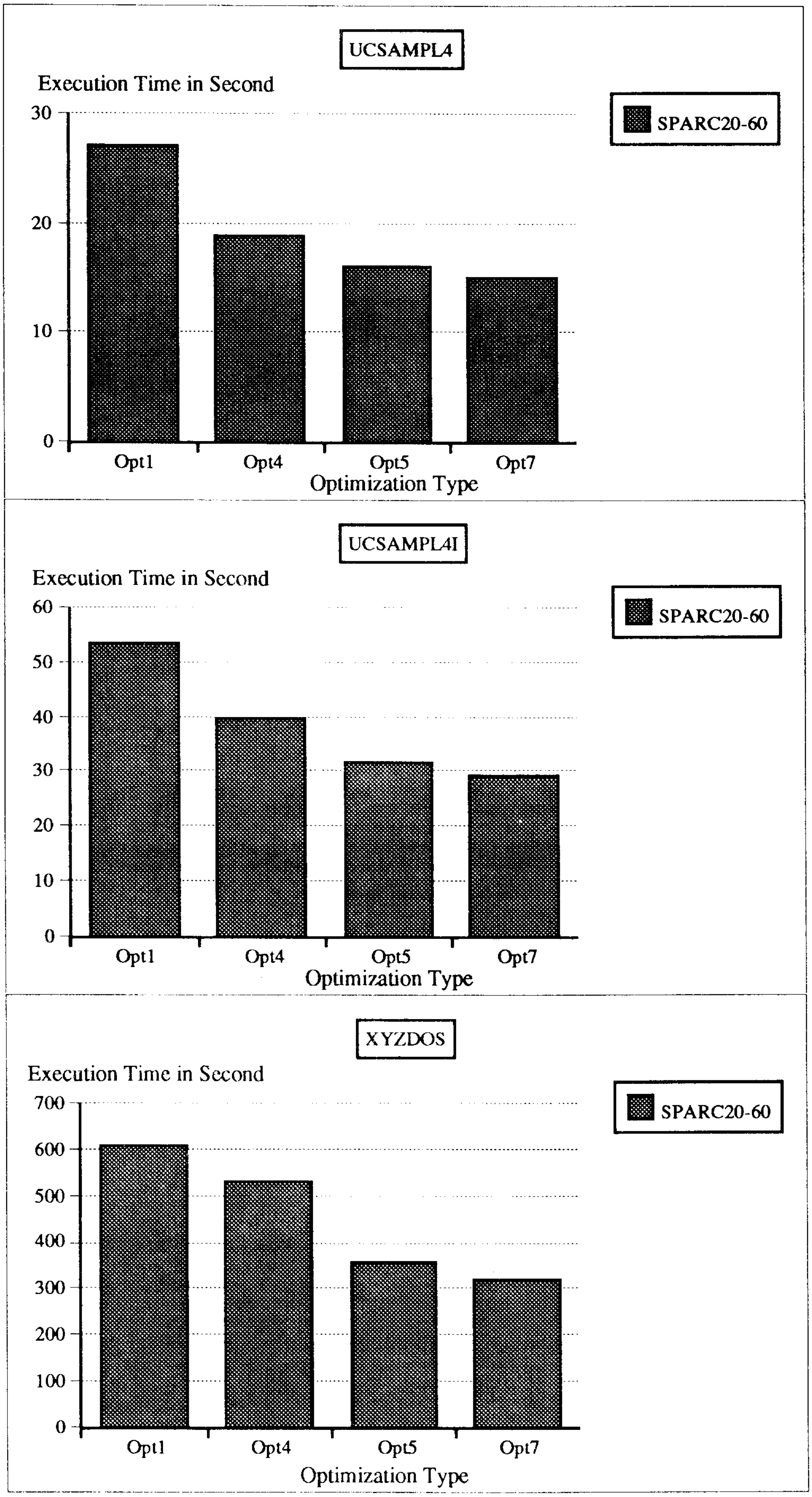


Fig. 7 EGS4 Benchmark Results on Fujitsu Computer

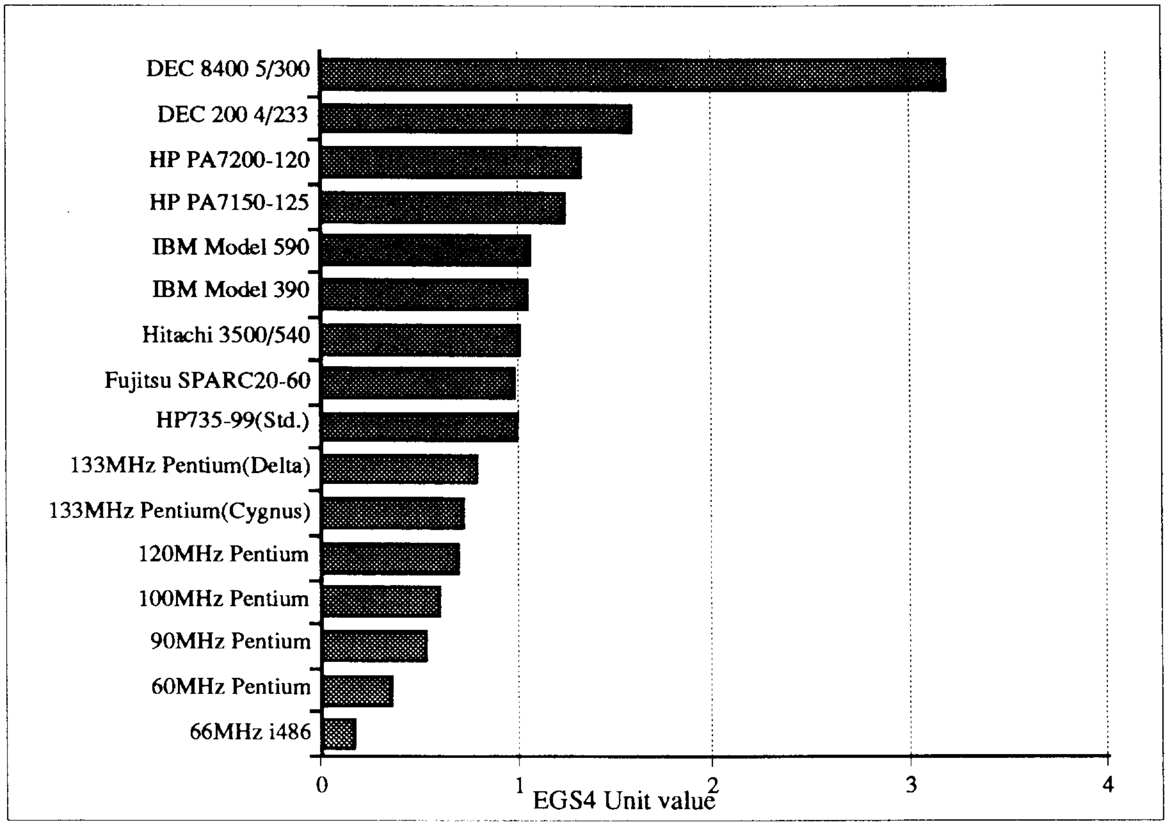


Fig. 8 EGS4 Unit

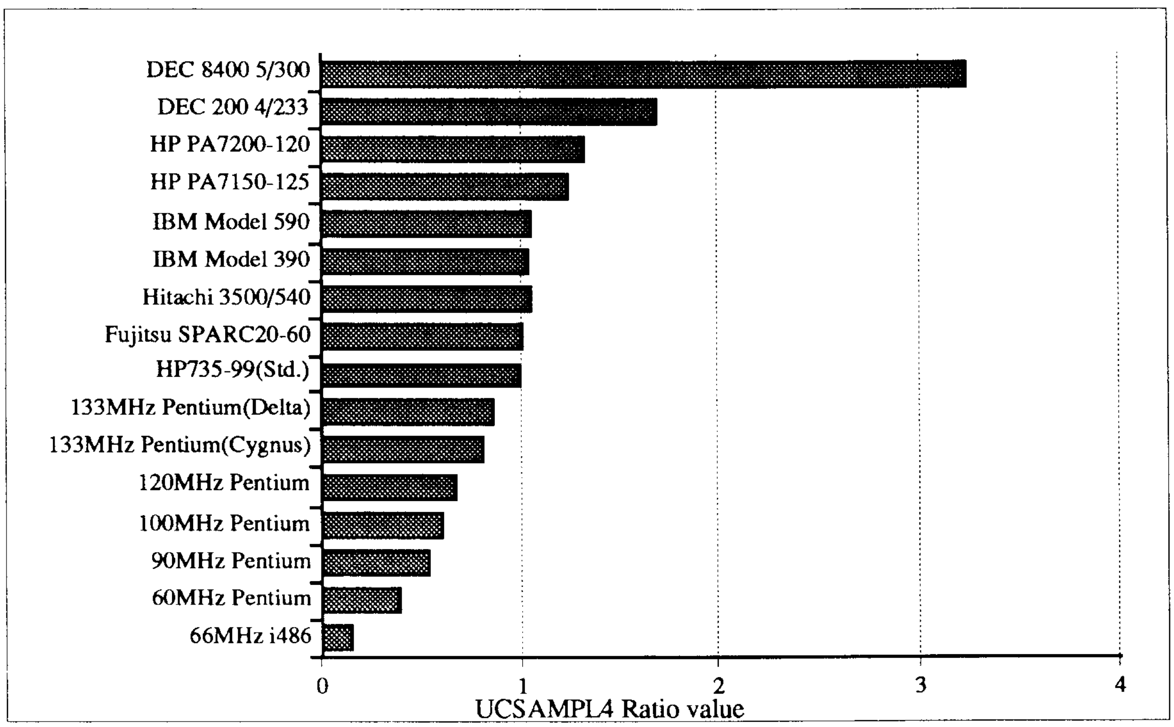


Fig. 9 UCSAMPL4 Ratio

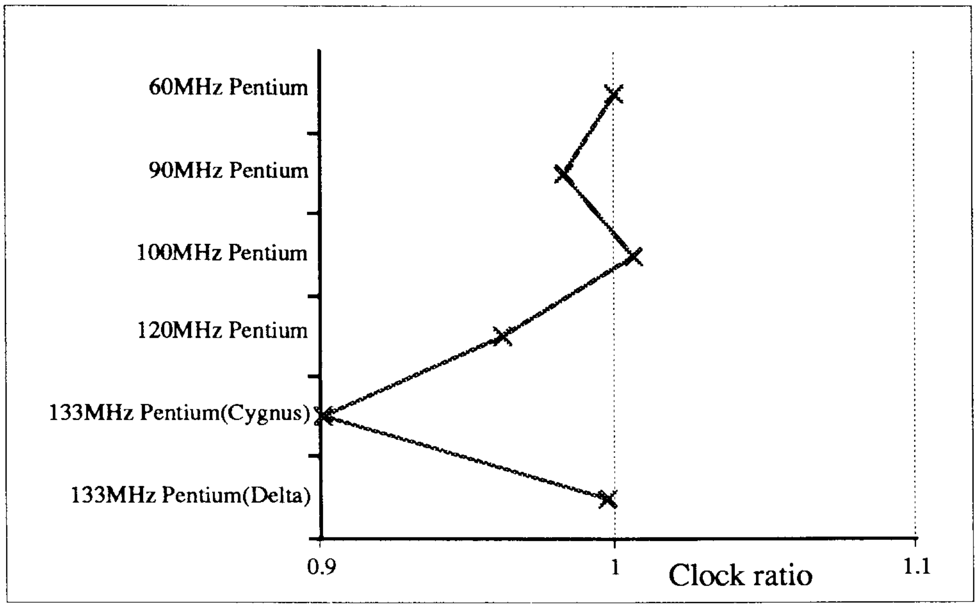


Fig. 10 Clock Dependency of EGS4 Unit on Pentium PCs

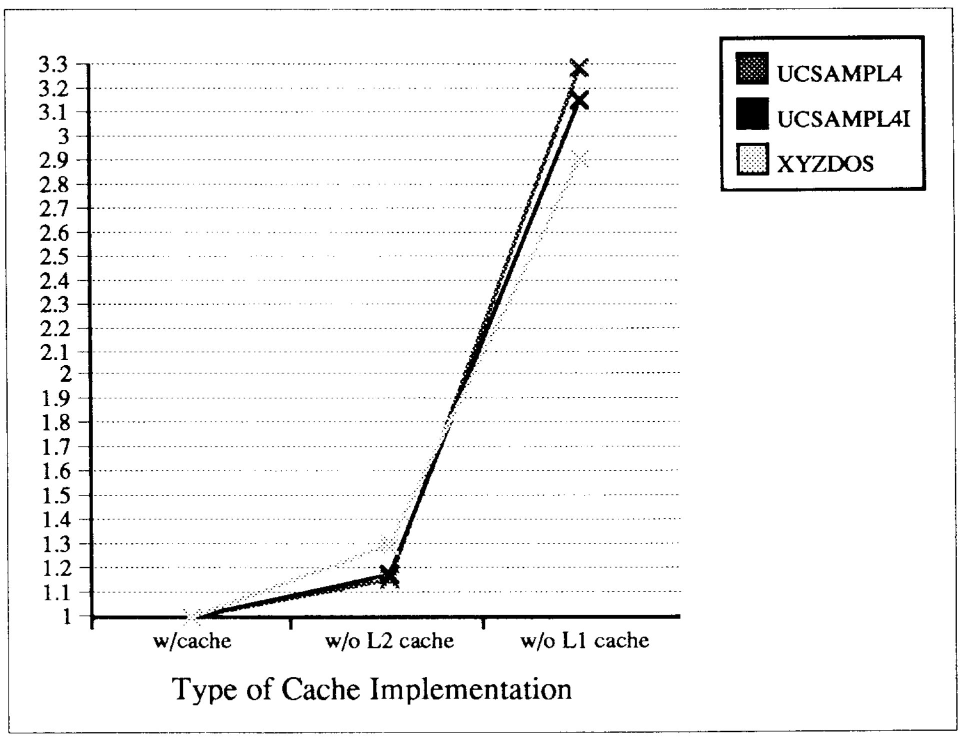


Fig. 11 Cache Dependency of EGS4 Unit on Pentium PC

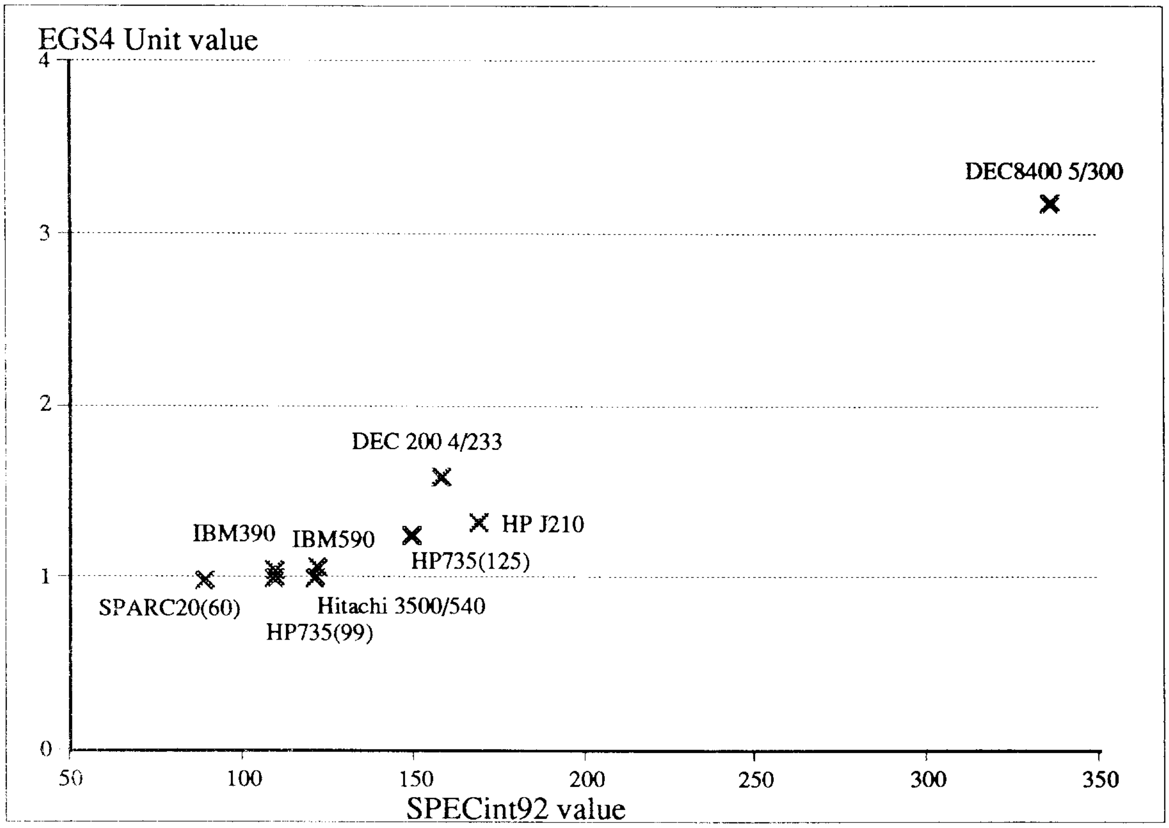


Fig. 12 Correlation of EGS4 Unit and SPECint92

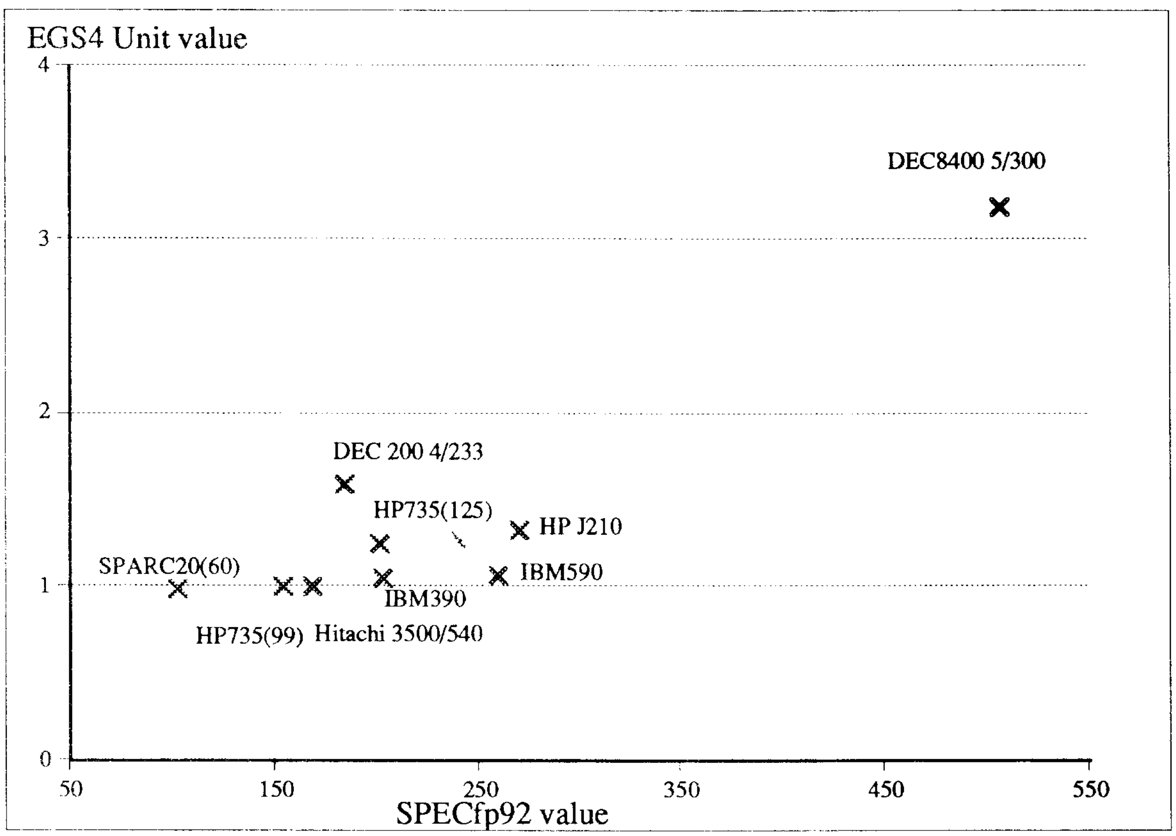


Fig. 13 Correlation of EGS4 Unit and SPECfp92

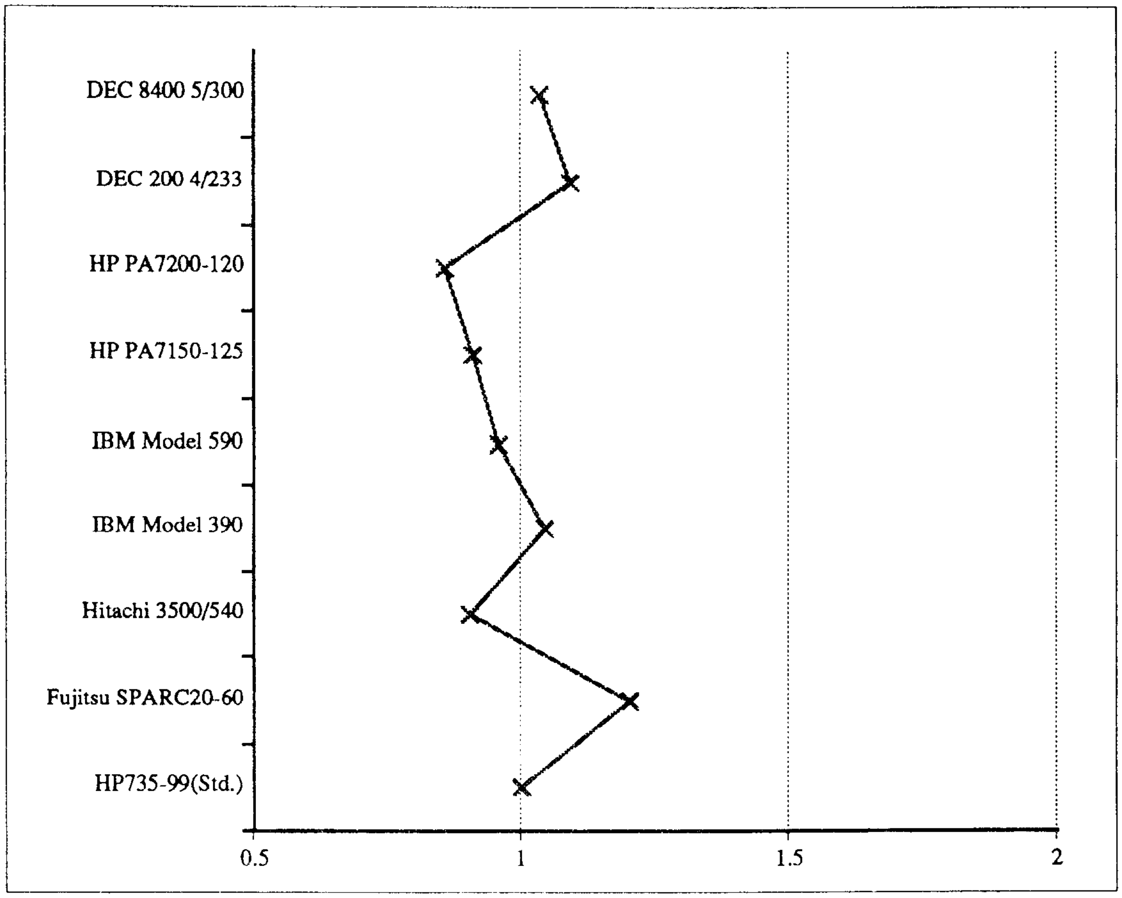


Fig 14 SPECint92 ratio of EGS4 Unit

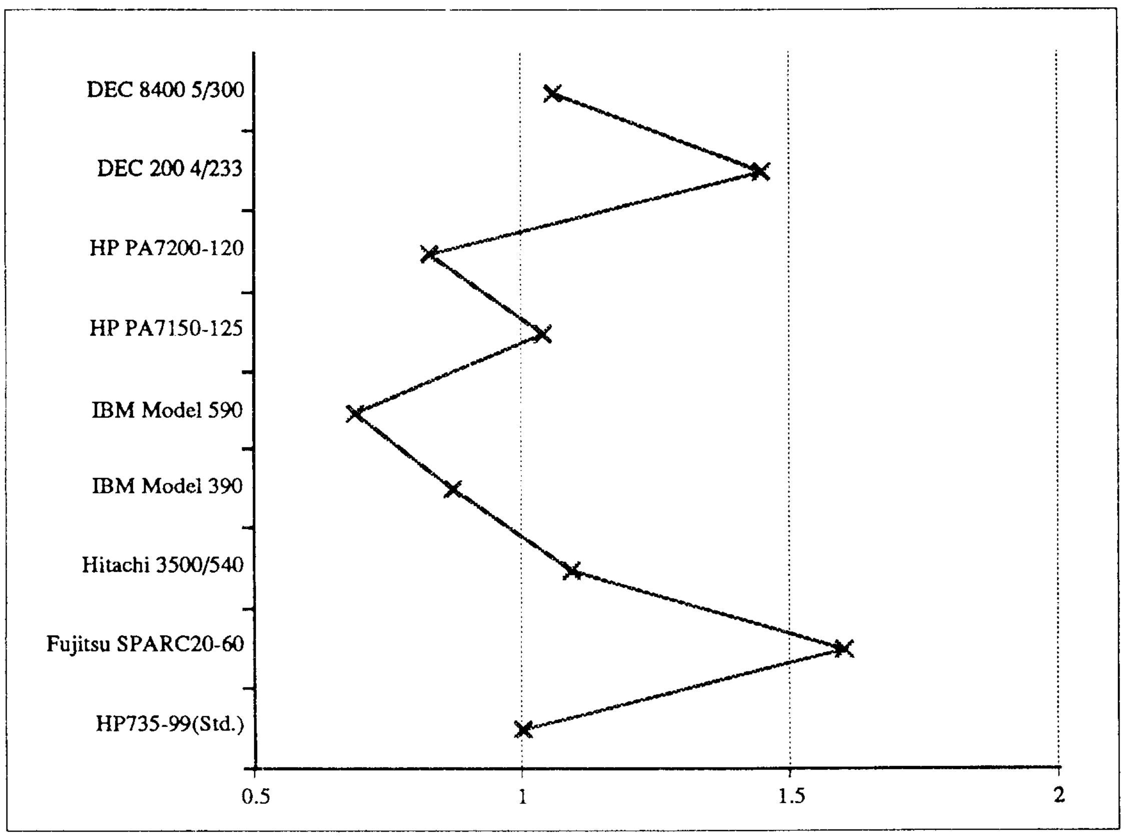


Fig 15 SPECfp92 ratio of EGS4 Unit