# Appendix: Detailed Results

This document includes the detailed results for the paper "High-Bandwidth Address Translation for Multiple-Issue Processors", by Todd M. Austin and Gurindar S. Sohi in ISCA-23, May 1996.

| Program | Inputs/Options | Insts (Mil.) | Loads (Mil.) | Stores (Mil.) | Inst/Cycle | | (Ld+St)/Cycle | | Br Pred Rate (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Issue | C'mit | Issue | C'mit | |
| Compress | in | 62.0 | 15.8 | 6.1 | 3.65 | 1.96 | 1.30 | 0.69 | 89.7 |
| Doduc | doducin | 1,375.1 | 330.4 | 130.2 | 2.16 | 1.76 | 0.71 | 0.59 | 86.6 |
| Espresso | -t cps.in | 517.5 | 116.5 | 32.7 | 4.48 | 2.90 | 1.32 | 0.84 | 90.2 |
| GCC | -O 1stmt.i | 110.6 | 26.4 | 16.5 | 3.56 | 1.87 | 1.32 | 0.72 | 80.2 |
| Ghostscript | -dNOPAUSE -sDEVICE=ppm fast-addr.ps -c quit | 625.2 | 109.1 | 53.3 | 2.76 | 2.18 | 0.73 | 0.55 | 93.3 |
| MPEG_play | coil.mpg | 529.6 | 114.9 | 47.9 | 4.10 | 2.82 | 1.19 | 0.87 | 85.9 |
| Perl | tests.pl | 231.5 | 57.7 | 37.2 | 2.85 | 1.43 | 1.10 | 0.57 | 81.2 |
| TFFT | MEXPONENT=20, ITER=1 | 959.8 | 136.6 | 89.4 | 2.69 | 1.79 | 0.62 | 0.42 | 79.9 |
| Tomcatv | N=129 | 359.7 | 90.9 | 18.3 | 3.64 | 2.72 | 1.00 | 0.83 | 86.6 |
| Xlisp | li-input.lsp | 962.7 | 289.2 | 171.6 | 4.17 | 2.52 | 1.86 | 1.21 | 87.9 |

Table 1: Program Execution Performance. Instruction, load, and store counts include only non-speculative operations. The columns labeled *Issue* and *C'mit* indicate the average number of operations issued and committed per cycle, respectively, on the baseline 8-way out-of-order issue processor simulator.

| Program | Multi-ported | | | | Multi-level/Pretranslated | | | | Interleaved | | | Piggybacked | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T4-IPC | T4 | T2 | T1 | M16 | M8 | M4 | P8 | I8 | I4 | X4 | PB2 | PB1 | I4/PB |
| Compress | 1.962 | 1.000 | 0.941 | 0.683 | 0.908 | 0.891 | 0.871 | 0.953 | 0.879 | 0.861 | 0.862 | 0.998 | 0.943 | 0.994 |
| Doduc | 1.757 | 1.000 | 0.962 | 0.848 | 1.000 | 0.994 | 0.985 | 0.984 | 0.935 | 0.929 | 0.934 | 0.997 | 0.974 | 0.996 |
| Espresso | 2.900 | 1.000 | 0.934 | 0.699 | 1.000 | 1.000 | 0.981 | 0.983 | 0.893 | 0.868 | 0.874 | 0.994 | 0.916 | 0.986 |
| GCC | 1.869 | 1.000 | 0.910 | 0.660 | 1.000 | 0.977 | 0.925 | 0.990 | 0.883 | 0.857 | 0.851 | 0.990 | 0.888 | 0.984 |
| Ghostscript | 2.178 | 1.000 | 0.959 | 0.819 | 0.999 | 0.990 | 0.972 | 0.943 | 0.931 | 0.921 | 0.954 | 0.999 | 0.974 | 0.989 |
| MPEG_play | 2.822 | 1.000 | 0.908 | 0.692 | 0.958 | 0.937 | 0.850 | 0.880 | 0.876 | 0.846 | 0.843 | 0.972 | 0.865 | 0.980 |
| Perl | 1.434 | 1.000 | 0.937 | 0.734 | 0.997 | 0.972 | 0.925 | 0.976 | 0.939 | 0.905 | 0.906 | 0.992 | 0.904 | 0.983 |
| TFFT | 1.790 | 1.000 | 0.957 | 0.847 | 0.991 | 0.989 | 0.986 | 1.000 | 0.954 | 0.950 | 0.946 | 0.990 | 0.969 | 0.989 |
| Tomcatv | 2.721 | 1.000 | 0.960 | 0.787 | 1.000 | 0.994 | 0.955 | 0.908 | 0.935 | 0.934 | 0.974 | 0.998 | 0.965 | 0.996 |
| Xlisp | 2.523 | 1.000 | 0.876 | 0.551 | 0.999 | 1.000 | 0.972 | 0.987 | 0.834 | 0.806 | 0.815 | 0.992 | 0.861 | 0.986 |
| RTW Avg | 2.094 | 1.000 | 0.940 | 0.767 | 0.994 | 0.988 | 0.965 | 0.972 | 0.916 | 0.902 | 0.909 | 0.993 | 0.939 | 0.990 |

Table 2: Relative Performance on Baseline Simulator. Results shown are run-time weighted average IPCs normalized to the performance of design T4. All experiments were run on an 8-way out-of-order issue processor simulator with 32 registers and 4k pages.

| Program | Fully-Associative | | | | | | Set-Associative (128 entries) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4 entries | 8 entries | 16 entries | 32 entries | 64 entries | 128 entries | 8-way | 16-way | 32-way | 64-way |
| Compress | 18.8 | 16.0 | 13.4 | 9.8 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Doduc | 7.7 | 3.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Espresso | 3.5 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| GCC | 11.5 | 3.7 | 0.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ghostscript | 8.0 | 3.3 | 0.3 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MPEG_play | 37.7 | 14.4 | 12.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Perl | 12.8 | 5.4 | 1.3 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| TFFT | 23.3 | 5.3 | 0.1 | 0.1 | 0.1 | 0.1 | 2.7 | 0.1 | 0.1 | 0.1 |
| Tomcatv | 15.8 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Xlisp | 4.4 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| RTW Avg | 13.8 | 4.6 | 1.4 | 0.2 | 0.1 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 |

Table 3: TLB miss rates. All values shown indicate percent of all references that miss. The row labeled RTW Avg is the run-time weighted average miss rate over all the benchmarks (weighted by the run-time of configuration T4). The 4, 8, and 16 entry TLBs are managed with LRU replacement, and the 32, 64, and 128 entry TLBs are managed with random replacement.

| | | | | 8-Way In-order Issue, 4k page | | | | | 8-Way Out-of-Order Issue, 8k page | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Insts | Loads | Stores | Inst/Cycle | | (Ld+St)/Cycle | | Br Pred | Inst/Cycle | | (Ld+St)/Cycle | | Br Pred |
| Program | (Mil.) | (Mil.) | (Mil.) | Issue | C'mit | Issue | C'mit | Rate (%) | Issue | C'mit | Issue | C'mit | Rate (%) |
| Compress | 62.0 | 15.8 | 6.1 | 1.31 | 1.23 | 0.45 | 0.43 | 89.4 | 3.65 | 1.96 | 1.30 | 0.69 | 89.7 |
| Doduc | 1,375.1 | 330.4 | 130.2 | 1.01 | 0.97 | 0.33 | 0.32 | 86.4 | 2.16 | 1.76 | 0.71 | 0.59 | 86.7 |
| Espresso | 517.5 | 116.5 | 32.7 | 1.50 | 1.41 | 0.43 | 0.41 | 88.8 | 4.48 | 2.90 | 1.32 | 0.84 | 90.2 |
| GCC | 110.6 | 26.4 | 16.5 | 1.55 | 1.27 | 0.56 | 0.49 | 78.8 | 3.56 | 1.87 | 1.32 | 0.72 | 80.2 |
| Ghostscript | 625.2 | 109.1 | 53.3 | 1.36 | 1.30 | 0.35 | 0.33 | 94.3 | 2.76 | 2.18 | 0.73 | 0.55 | 93.3 |
| MPEG_play | 529.6 | 114.9 | 47.9 | 1.36 | 1.29 | 0.42 | 0.40 | 84.6 | 4.11 | 2.83 | 1.17 | 0.86 | 86.0 |
| Perl | 231.5 | 57.7 | 37.2 | 1.32 | 1.10 | 0.52 | 0.44 | 79.4 | 2.85 | 1.43 | 1.10 | 0.57 | 81.2 |
| TFFT | 959.8 | 136.6 | 89.4 | 1.17 | 1.04 | 0.27 | 0.24 | 84.5 | 2.70 | 1.79 | 0.62 | 0.42 | 79.0 |
| Tomcatv | 359.7 | 90.9 | 18.3 | 1.12 | 1.09 | 0.34 | 0.33 | 86.0 | 3.67 | 2.73 | 1.00 | 0.83 | 86.6 |
| Xlisp | 962.7 | 289.2 | 171.6 | 1.55 | 1.42 | 0.73 | 0.68 | 87.2 | 4.17 | 2.52 | 1.86 | 1.21 | 88.0 |

Table 4: Program Execution Performance. Instruction, load, and store counts include only non-speculative operations. The columns labeled *Issue* and *C'mit* indicate the average number of operations issued and committed per cycle, respectively.

| | Multi-ported | | | | Multi-level/Pretranslated | | | | Interleaved | | | Piggybacked | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Program | T4-IPC | T4 | T2 | T1 | M16 | M8 | M4 | P8 | I8 | I4 | X4 | PB2 | PB1 | I4/PB |
| Compress | 1.230 | 1.000 | 0.985 | 0.924 | 0.981 | 0.975 | 0.959 | 0.967 | 0.930 | 0.930 | 0.931 | 1.000 | 1.000 | 1.000 |
| Doduc | 0.966 | 1.000 | 0.992 | 0.945 | 0.997 | 0.981 | 0.937 | 0.960 | 0.964 | 0.963 | 0.974 | 0.996 | 0.994 | 0.995 |
| Espresso | 1.412 | 1.000 | 0.975 | 0.897 | 1.000 | 0.998 | 0.981 | 0.922 | 0.952 | 0.942 | 0.948 | 0.999 | 0.946 | 0.988 |
| GCC | 1.273 | 1.000 | 0.980 | 0.902 | 0.995 | 0.975 | 0.928 | 0.946 | 0.936 | 0.931 | 0.934 | 0.999 | 0.985 | 0.996 |
| Ghostscript | 1.303 | 1.000 | 0.992 | 0.952 | 0.998 | 0.984 | 0.961 | 0.964 | 0.961 | 0.959 | 0.961 | 1.000 | 0.993 | 0.995 |
| MPEG_play | 1.286 | 1.000 | 0.984 | 0.885 | 0.951 | 0.937 | 0.859 | 0.941 | 0.958 | 0.949 | 0.957 | 0.992 | 0.919 | 0.998 |
| Perl | 1.098 | 1.000 | 0.986 | 0.929 | 0.992 | 0.972 | 0.936 | 0.958 | 0.959 | 0.949 | 0.966 | 0.999 | 0.987 | 0.994 |
| TFFT | 1.040 | 1.000 | 0.991 | 0.983 | 0.999 | 0.996 | 0.968 | 0.984 | 0.984 | 0.977 | 0.982 | 1.000 | 0.992 | 1.000 |
| Tomcatv | 1.094 | 1.000 | 1.000 | 0.972 | 1.000 | 1.000 | 0.931 | 0.951 | 0.995 | 0.994 | 0.904 | 1.000 | 0.976 | 0.999 |
| Xlisp | 1.419 | 1.000 | 0.975 | 0.893 | 1.000 | 0.992 | 0.936 | 0.988 | 0.937 | 0.937 | 0.941 | 0.999 | 0.994 | 1.000 |
| RTW Avg | 1.156 | 1.000 | 0.988 | 0.937 | 0.994 | 0.984 | 0.935 | 0.959 | 0.963 | 0.959 | 0.960 | 0.998 | 0.982 | 0.997 |

Table 5: Relative Performance with In-order Issue.

| | Multi-ported | | | | Multi-level/Pretranslated | | | | Interleaved | | | Piggybacked | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Program | T4-IPC | T4 | T2 | T1 | M16 | M8 | M4 | P8 | I8 | I4 | X4 | PB2 | PB1 | I4/PB |
| Compress | 1.962 | 1.000 | 0.941 | 0.682 | 0.928 | 0.900 | 0.874 | 0.955 | 0.879 | 0.833 | 0.805 | 0.998 | 0.944 | 0.992 |
| Doduc | 1.756 | 1.000 | 0.991 | 0.867 | 1.000 | 1.000 | 1.000 | 0.997 | 0.959 | 0.944 | 0.944 | 1.000 | 0.996 | 0.997 |
| Espresso | 2.899 | 1.000 | 0.934 | 0.699 | 0.997 | 1.000 | 1.000 | 0.984 | 0.885 | 0.863 | 0.868 | 1.000 | 0.952 | 0.996 |
| GCC | 1.868 | 1.000 | 0.911 | 0.660 | 1.000 | 0.990 | 0.939 | 0.992 | 0.873 | 0.847 | 0.844 | 0.992 | 0.891 | 0.982 |
| Ghostscript | 2.179 | 1.000 | 0.959 | 0.819 | 0.999 | 0.994 | 0.978 | 0.970 | 0.941 | 0.925 | 0.935 | 0.999 | 0.987 | 0.997 |
| MPEG_play | 2.827 | 1.000 | 0.907 | 0.691 | 0.978 | 0.974 | 0.872 | 0.898 | 0.875 | 0.852 | 0.849 | 0.994 | 0.886 | 1.000 |
| Perl | 1.435 | 1.000 | 0.936 | 0.733 | 1.000 | 0.980 | 0.933 | 0.990 | 0.939 | 0.914 | 0.921 | 0.993 | 0.907 | 0.981 |
| TFFT | 1.792 | 1.000 | 0.957 | 0.846 | 0.991 | 0.988 | 0.987 | 1.000 | 0.953 | 0.934 | 0.933 | 0.990 | 0.968 | 0.996 |
| Tomcatv | 2.734 | 1.000 | 0.958 | 0.783 | 1.000 | 0.992 | 0.959 | 0.943 | 0.939 | 0.937 | 0.972 | 0.994 | 0.987 | 0.997 |
| Xlisp | 2.523 | 1.000 | 0.875 | 0.551 | 0.999 | 0.999 | 0.977 | 0.989 | 0.839 | 0.707 | 0.707 | 0.992 | 0.862 | 0.969 |
| RTW Avg | 2.095 | 1.000 | 0.948 | 0.772 | 0.996 | 0.992 | 0.975 | 0.982 | 0.924 | 0.890 | 0.893 | 0.996 | 0.952 | 0.992 |

Table 6: Relative Performance with 8k Pages.

| | | | | 8-Way Out-of-order Issue, 8 int/8 fp registers | | | | |
|---|---|---|---|---|---|---|---|---|
| | Insts | Loads | Stores | Inst/Cycle | | (Ld+St)/Cycle | | Br Pred |
| Program | (Mil.) | (Mil.) | (Mil.) | Issue | C'mit | Issue | C'mit | Rate (%) |
| Compress | 72.9 | 18.6 | 6.1 | 3.64 | 2.12 | 1.22 | 0.72 | 90.2 |
| Doduc | 1,616.4 | 457.1 | 227.0 | 2.35 | 1.93 | 0.97 | 0.82 | 86.4 |
| Espresso | 621.1 | 182.2 | 65.1 | 4.46 | 3.38 | 1.78 | 1.33 | 92.5 |
| GCC | 119.5 | 33.1 | 19.8 | 3.64 | 1.96 | 1.57 | 0.87 | 80.8 |
| Ghostscript | 651.5 | 126.9 | 59.1 | 3.05 | 1.96 | 0.96 | 0.56 | 89.5 |
| MPEG_play | 704.3 | 225.1 | 101.6 | 4.31 | 2.80 | 1.83 | 1.30 | 81.1 |
| Perl | 241.0 | 61.6 | 42.4 | 2.86 | 1.46 | 1.23 | 0.63 | 81.4 |
| TFFT | 1,350.0 | 402.4 | 181.6 | 3.04 | 2.24 | 1.15 | 0.97 | 79.4 |
| Tomcatv | 1,969.8 | 355.3 | 131.7 | 5.47 | 5.44 | 1.35 | 1.35 | 89.3 |
| Xlisp | 946.6 | 280.0 | 165.3 | 4.22 | 2.59 | 1.87 | 1.20 | 89.3 |

Table 7: Program Execution Performance.

| | Multi-ported | | | | Multi-level/Pretranslated | | | | Interleaved | | | Piggybacked | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Program | T4-IPC | T4 | T2 | T1 | M16 | M8 | M4 | P8 | I8 | I4 | X4 | PB2 | PB1 | I4/PB |
| Compress | 2.120 | 1.000 | 0.947 | 0.698 | 0.932 | 0.913 | 0.887 | 0.967 | 0.900 | 0.883 | 0.888 | 0.997 | 0.929 | 0.994 |
| Doduc | 1.930 | 1.000 | 0.948 | 0.759 | 0.999 | 0.994 | 0.986 | 0.980 | 0.893 | 0.878 | 0.883 | 0.997 | 0.949 | 0.993 |
| Espresso | 3.383 | 1.000 | 0.841 | 0.540 | 1.000 | 0.997 | 0.949 | 0.815 | 0.814 | 0.728 | 0.731 | 0.964 | 0.799 | 0.946 |
| GCC | 1.956 | 1.000 | 0.885 | 0.610 | 1.000 | 0.979 | 0.924 | 0.890 | 0.855 | 0.827 | 0.819 | 0.985 | 0.857 | 0.980 |
| Ghostscript | 1.959 | 1.000 | 0.938 | 0.800 | 1.000 | 0.988 | 0.967 | 0.959 | 0.904 | 0.893 | 0.910 | 0.996 | 0.938 | 0.983 |
| MPEG_play | 2.796 | 1.000 | 0.854 | 0.566 | 0.984 | 0.971 | 0.922 | 0.910 | 0.811 | 0.749 | 0.742 | 0.962 | 0.811 | 0.961 |
| Perl | 1.455 | 1.000 | 0.927 | 0.708 | 1.000 | 0.977 | 0.936 | 0.941 | 0.938 | 0.896 | 0.893 | 0.991 | 0.897 | 0.983 |
| TFFT | 2.240 | 1.000 | 0.901 | 0.652 | 1.000 | 0.998 | 0.977 | 0.996 | 0.773 | 0.754 | 0.759 | 1.000 | 0.874 | 0.958 |
| Tomcatv | 5.445 | 1.000 | 0.940 | 0.631 | 1.000 | 0.998 | 0.984 | 0.677 | 0.723 | 0.710 | 0.713 | 0.998 | 0.879 | 0.974 |
| Xlisp | 2.590 | 1.000 | 0.869 | 0.543 | 1.000 | 0.999 | 0.964 | 0.890 | 0.842 | 0.815 | 0.822 | 0.981 | 0.862 | 0.974 |
| RTW Avg | 2.594 | 1.000 | 0.912 | 0.670 | 0.998 | 0.992 | 0.967 | 0.917 | 0.837 | 0.811 | 0.816 | 0.992 | 0.892 | 0.975 |

Table 8: Relative Performance with Fewer Registers (8 int/8 fp).