# Cache Performance of the Integer SPEC Benchmarks on a RISC †

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*ABSTRACT*

SPEC is a new set of benchmark programs designed to measure a computer system's performance. The performance measured by benchmarks is strongly affected by the existence and configuration of cache memory. In this paper we evaluate the cache miss ratio of the Integer SPEC benchmarks. We show that the cache miss ratio depends strongly on the program, and that large caches are not completely exercised by these benchmarks.

## 1. Introduction

The SPEC benchmarks are a new set of benchmark programs designed to evaluate the performance of computer systems [9]. In the design of this set, considerable effort is made so that the results are indicative from the expected performance in environments like Computer Aided Software Engineering and Computer Aided Engineering. To achieve this goal, public domain real applications from the above areas are used. The performance measured is scaled to the performance of the VAX 11/780 for each program in the set, and the ratios are averaged using the geometric mean as proposed in [1]. The first release of the SPEC benchmarks consists of ten programs: GNU C compiler, Eqntott, Xlisp, Espresso, Spice 2g6, Doduc, Nasa7, Matrix300, Fpppp and TomcatV. The first four are integer-intensive programs written in C, and the rest are floating-point-intensive programs written in Fortran.

Since most high-performance computer systems include one or more caches to reduce the average memory access time and therefore to improve performance [7], a question that can be asked is what is the effect of caches on the performance measured by the benchmark programs. Knowing the cache behavior of the benchmarking programs, one can predict the performance change for a given change in the memory hierarchy. However, the performance of a system will not be accurately predictable if the cache behavior shows sharp changes around some parameter values, because small changes in a cache configuration can yield large changes in the measured performance. Also important are cache configuration sizes where miss ratios become negligible, since improving cache parameters beyond these sizes will not improve the performance measured by these benchmarks.

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To evaluate the cache performance of the SPEC benchmarks, the four integer-intensive programs were traced and simulated for a large number of cache configurations. The programs were compiled on a DECstation 3100 based on the MIPS R2000 architecture running the Ultrix operating system.

## 2. Tracing and simulation

The traces were obtained using the Abstract Execution method [6], for speed and compression reasons. AE poses some restrictions on the traces that can be obtained, the most important of which are that they can only be single process traces, that the operating system calls cannot be traced, and that the GNU C compiler must be used. Even though AE can trace through library calls, the standard C libraries were not traced in this simulation. However, we feel that the programs do not use them very much and the difference in the results would be small. All programs were compiled with the optimizing flag enabled. For the cache simulation, the *All Associativity* simulation algorithm [5] as implemented in Tycho [4] was used.

The cache parameters used throughout the simulation were: cache size from 1 Kbyte up to 1 Mbyte, associativity from 1 (direct mapped) up to 8 way set-associative, and block size from 16 up to 256 bytes. All steps through these parameters are in factors of two. The replacement algorithm used was LRU and the set-mapping function was bit selection. All the above cache configurations were simulated for instruction, data and unified caches. The reported miss ratio is the total number of misses for the entire execution of the program, divided by the total number of references. Since the entire execution of the program is traced, the cold misses are included in the miss ratio. For Gcc and Espresso, that are run for several input files, the misses for all input files are summed and divided by the total number of references made. Due to time limitations, Espresso was simulated for only two of the eight input files that constitute the benchmark. The complete results are given in tabular form in the Appendix. In the results, a zero miss ratio means that the actual miss ratio is less than 0.0001. The total number of references for each program and the breakdown to instruction and data accesses is given in Table I.

Table I

| Program | Instruction | Data | Total |
|---|---|---|---|
| Eqntott | 1,129,738,935 | 288,685,224 | 1,418,424,159 |
| Xlisp | 1,280,576,271 | 592,700,976 | 1,873,277,247 |
| GNU C Compiler | 1,030,734,885 | 404,430,283 | 1,435,165,168 |
| Espresso | 1,415,583,519 | 394,076,087 | 1,809,659,606 |

## 3. Simulation results

This section present the four integer SPEC benchmarks in some detail and the corresponding simulation results. Additional insight can be obtained from Figures 1, 2 and 3 that give some of the results in a graphical form. Figure 1 plots the miss ratio as a function of cache size, Figure 2 plots the change in the miss ratio when the block size is doubled and Figure 3 plots the change in miss ratio when degree of associativity is doubled. For the rest of this section, the misses are divided into three categories [2]: *conflict* misses due to too many active blocks mapping to a fraction of the sets, *capacity* misses due to the fixed cache size and *compulsory* misses, the ones that first reference an item.

### 3.1. Eqntott

Eqntott is a program that translates a logical representation of a boolean equation to a truth table. The primary computation it performs is sorting, using the quicksort algorithm. Profiling this program shows that 95% of the time is spent in the quicksort routine. The size of data for the benchmark input is approximately 1.8 Mbytes.

The performance of the instruction cache for Eqntott can be seen clearly in the tables: for instruction caches of size larger than 2Kbytes the miss ratio is smaller than 0.0001. Since 95% of the time is spent in the quicksort routine, any cache of size larger than that will give the same performance.

The behavior of the data cache for Eqntott is a result of the nature of quicksort, which does not show a particularly high temporal locality, and of the large data size. Because of the low temporal locality of the algorithm, the capacity misses dominate and give a relatively high miss ratio for caches of size up to 256 Kbytes (0.03 for 128 Kbyte eight-way set-associative cache with 16 bytes block size). In the same range, the miss ratio is almost insensitive to changes in associativity as can be seen in Figure 3. For larger caches, associativity improves significantly the miss ratio. This behavior differs considerably from the one reported in previous studies [3], [5]. Furthermore, the miss ratio for medium and large size caches drops very quickly as the block size is increased, as the compulsory misses are reduced.

The unified cache performance of Eqntott, because of its degenerate instruction behavior, can be easily calculated by multiplying the data miss ratio by the fraction of data references of the program. This simple relation holds only when the number of sets is enough so that the conflicts between instruction and data accesses are rare.

### 3.2. Xlisp

Xlisp is a small implementation of a lisp interpreter, which also provides some object-oriented programming hooks. The input file is a small backtracking program that solves the Eight Queens problem. The small size of the program can be seen in the table for associativity 8: a cache size larger than 16 Kbytes for instruction and 32 Kbytes for data cache give miss ratio less than 0.0001.

For Xlisp, a small instruction cache gives a high miss ratio, because the interpreter shows low temporal locality (0.10 for 2Kbyte direct mapped cache with 16 bytes block size). However the miss ratio drops fast with the cache size and with the associativity, since the active part of the code is small.

The data accesses of Xlisp show greater temporal locality, so the miss ratio for small data caches is smaller than for instruction. It shows also significant spatial locality as can be seen in Figure 2. Increasing the block size improves the miss ratio considerably. Changes in the associativity are within previously reported limits, except for caches that are large enough to hold the entire working set, in which case the improvement can be larger than a factor of two (change from direct mapped to two-way set-associative cache of size larger than 32Kbytes).

The unified cache behavior follows the lines of the instruction and data cache behavior. The magnitude of the miss ratio is larger because of interference between instruction and data accesses. That interference can be reduced by increasing the associativity.

### 3.3. GNU C Compiler

The GNU C compiler or Gcc is the version 1.35 of the compiler as distributed by the Free Software Foundation. The benchmark consists of converting 19 preprocessed source files into optimized 68020 assembly language using the Sun-3 assembly format. This program is expected to predict accurately the compiling performance of the system in a software engineering environment.

Because Gcc is a big program, the miss ratios it shows are among the highest ones. The behavior of Gcc as can be seen in Figures 1, 2 and 3 is uniform and consistent with earlier studies [3], [5], [8] over a wide range of parameters. In that sense, Gcc is a well-behaved program and its behavior can be easily and accurately predicted or interpolated from incomplete data without large errors. Because of its size and structure, its demands from the memory hierarchy are significant.

### 3.4. Espresso

Finally, Espresso is a tool for generation and optimization of Programmable Logic Arrays from the Berkeley CAD software distribution. The main computations it performs are set operations like union and intersection, the sets being represented as arrays of bits. The set operations are then implemented as logical operations on these arrays. The benchmark consists of converting a set of eight input models into the corresponding optimized PLA output. For the two of the inputs that were traced, the breakdown in instruction and data references is shown in Table II.

Table II

| **Espresso** | | | |
|---|---|---|---|
| Input File | Instr | Data | Total |
| bca | 446,395,312 | 117,213,963 | 563,609,275 |
| tial | 969,188,207 | 276,862,124 | 1,246,050,331 |

Since Espresso is a relatively small program that spends a lot of its time in inner loops operating on arrays, the instruction cache miss ratio is small. The miss ratio is dominated by conflict misses, as can be seen by the effect of increasing the associativity. For Espresso, any two-way set-associative instruction cache of size larger than 32Kbytes has miss ratio less than 0.0001.

The array manipulation also limits the temporal locality of the data accesses and results in high miss ratio for data caches. However, the active data size is about 64 Kbytes, so caches of this or larger size have essentially the same performance.

Finally, the unified cache performance lies between the performance of split instruction and data caches. However, we should note that even though the results for Espresso appear to be consistent and reasonable, one should be careful when generalizing since only two of the eight inputs were simulated.

## 4. Conclusions

The cache performance of Integer SPEC benchmarks varies greatly depending on the program. With the major exception of Eqntott, the trends for small caches are similar. However, large caches show almost zero miss ratio for Xlisp and Espresso (0.002 for 64 Kbyte two-way set associative cache with 16 bytes block size). The behavior of Eqntott, because of its special structure, deviates greatly from the other programs. It favors configurations with a small instruction cache and a large data or unified cache. Overall, a split instruction/data cache of size 128 Kbytes each will give very low miss ratios for all programs and further improvements will not be clearly reflected in the SPEC results.

It might be arguable that, since the traces are not multiprogrammed as in most previous studies, the cache performance can be different. However, SPEC measure the performance in a practically single process environment, while the actual use of the machines is multiprogrammed. The Integer SPEC benchmarks, although a significant improvement over past standard benchmarks, will fail to completely exercise high performance memory hierarchies designed for such systems.

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**Figure 1**. Miss ratio as a function of cache size for two-way set associative caches and for block size 16 and 32 bytes. Note that the y-axis scale vary.

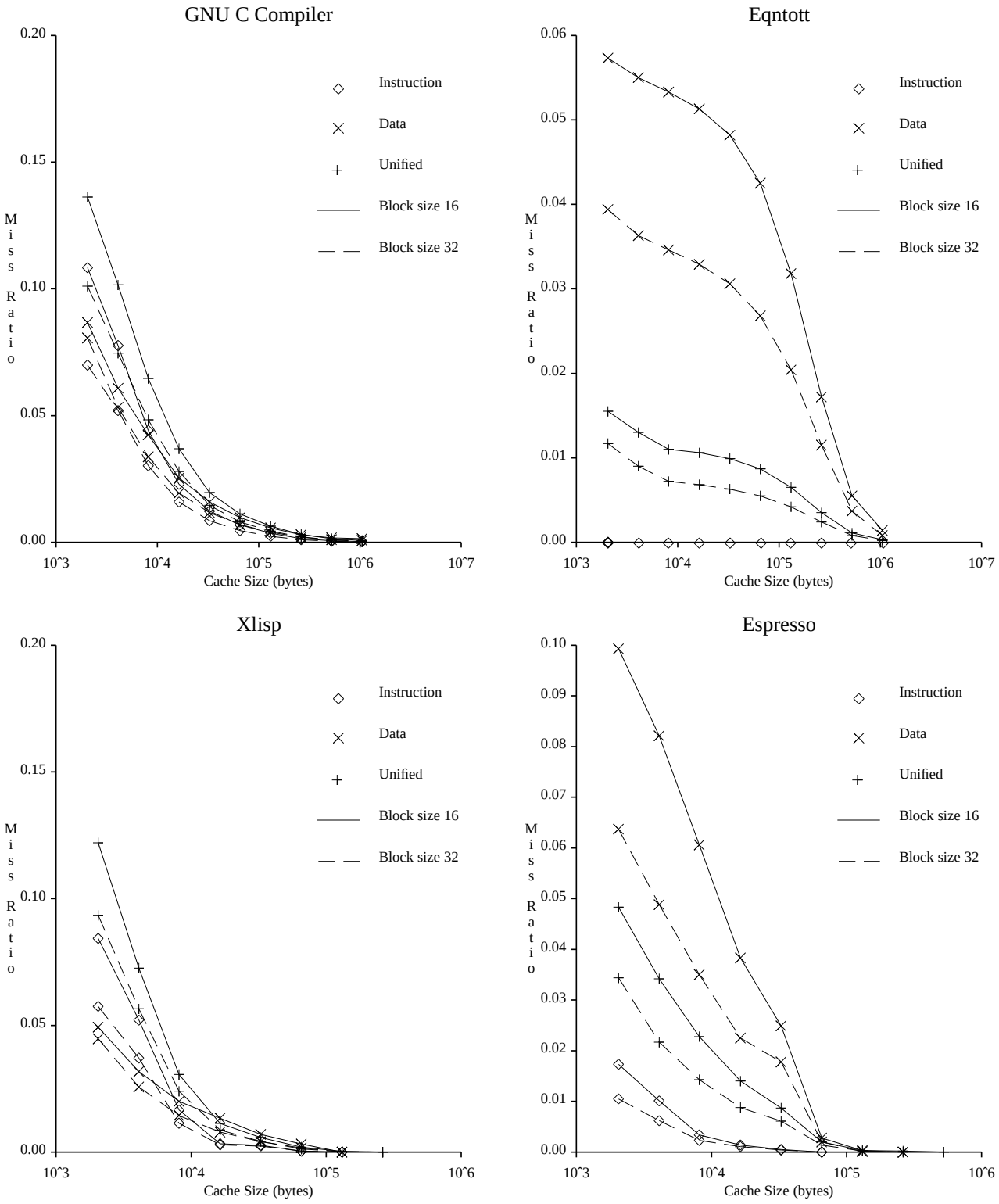


**Figure 2**. Change in miss ratio as a function of block size. Each point is the ratio of the miss ratio for a cache with block size 2*B divided by the miss ratio for a cache of block size B. This value gives the benefits of doubling the block size for two-way set-associative caches of size 16 and 64 Kbytes. Smaller values mean that doubling block size is more worthwhile. The instruction cache is omitted where the miss ratio is zero (Eqntott both sizes, Espresso 32Kbytes).

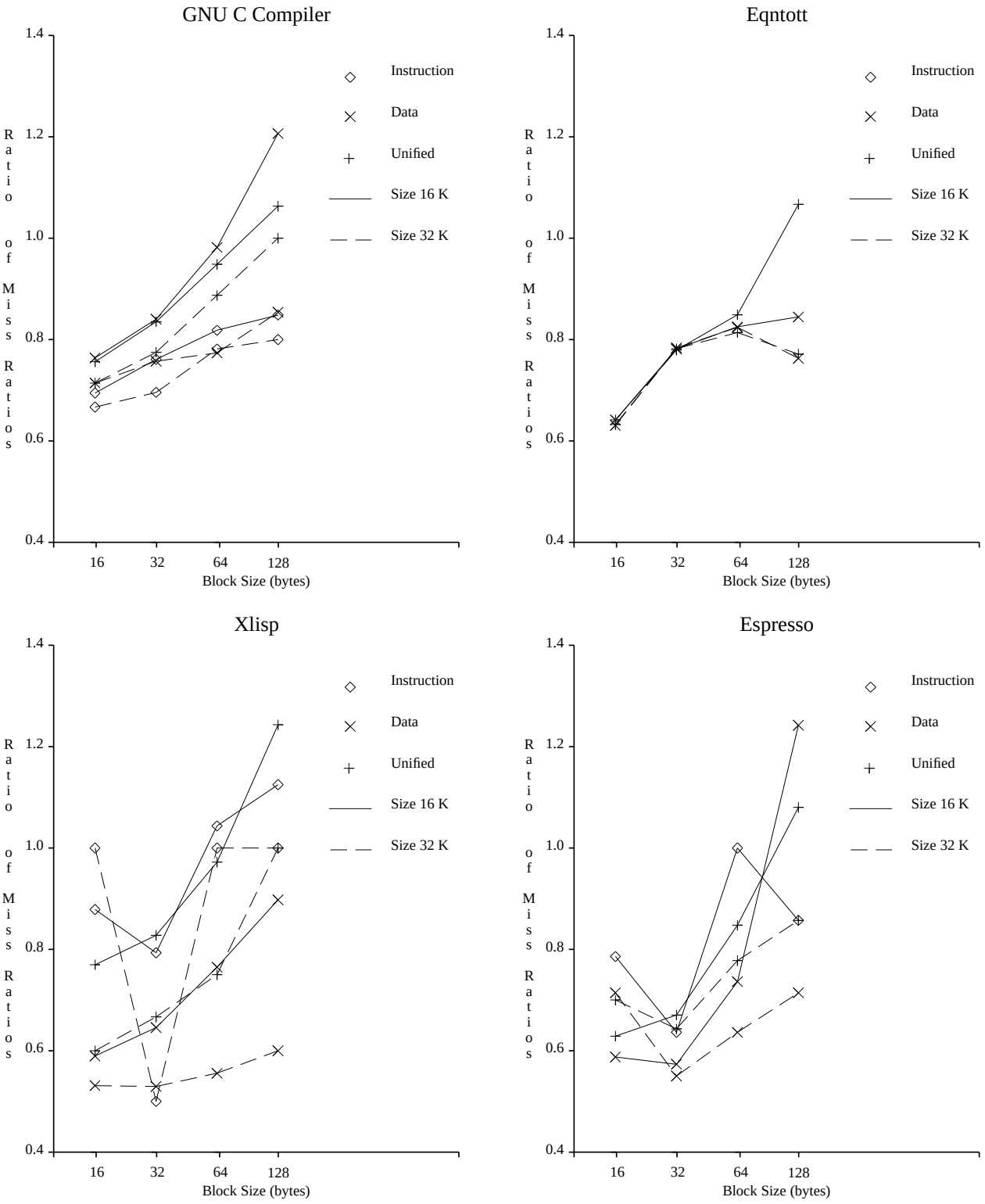
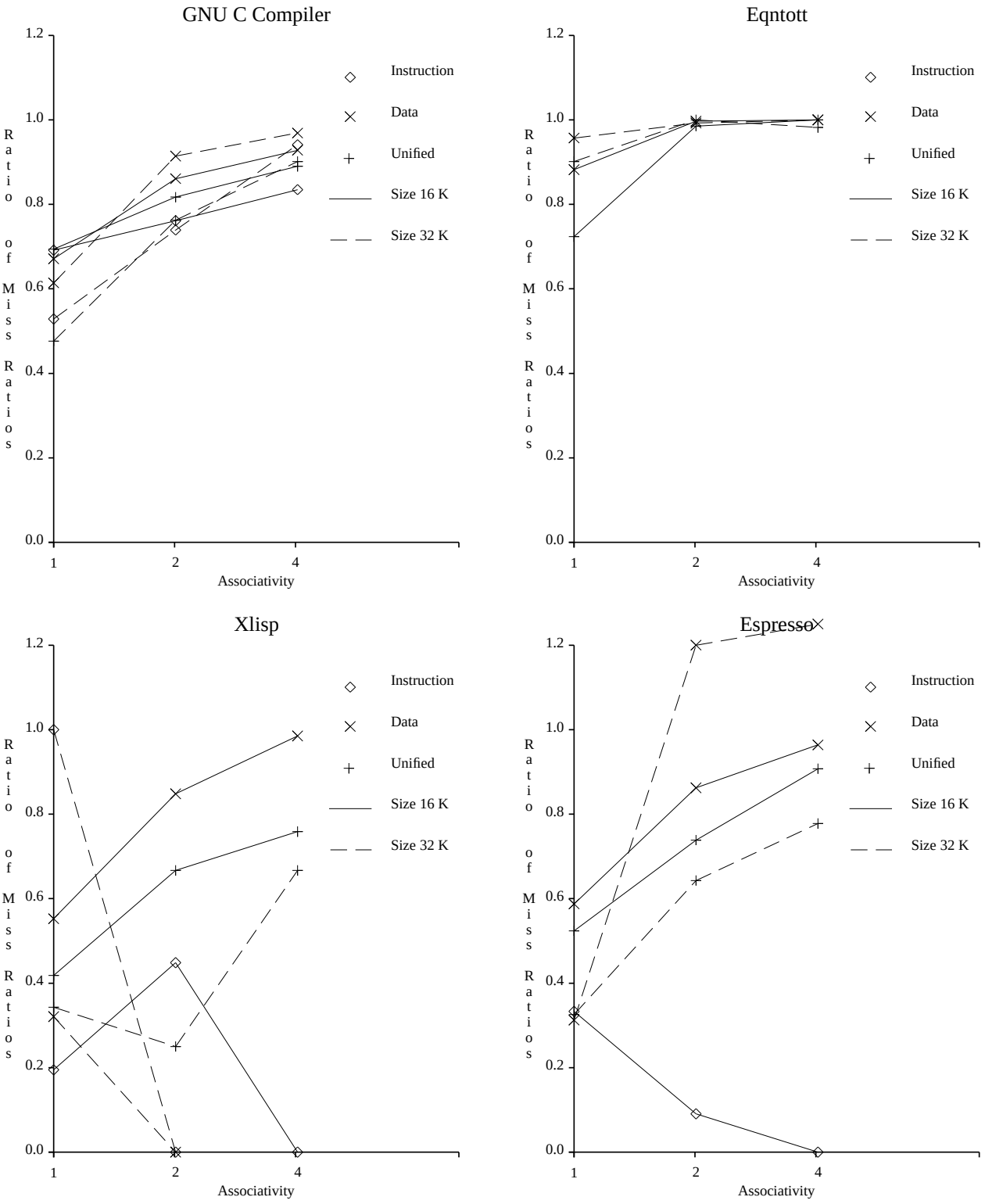


**Figure 3**. Change in miss ratio as a function of associativity. Each point is the ratio of miss ratio for a cache of associativity 2*A divided by the miss ratio for a cache of associativity A. This value gives the benefits of doubling the associativity for block size 32 bytes. Smaller values mean that doubling the associativity is more worthwhile. The instruction cache is omitted where the miss ratio is zero (Eqntott both sizes, Espresso 32Kbytes).



**Appendix. Complete tables of miss ratios.** Note that a value 0 means that the miss ratio is less than 0.0001.

**Eqntott : Associativity 1**

*Instruction*

| Size | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.0158 | 0.0116 | 0.0066 | 0.0066 | 0.0067 |
| 2K | 0.0158 | 0.0116 | 0.0066 | 0.0066 | 0.0066 |
| 4K | 0 | 0 | 0 | 0 | 0 |
| 8K | 0 | 0 | 0 | 0 | 0 |
| 16K | 0 | 0 | 0 | 0 | 0 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1073 | 0.1086 | 0.1748 | 0.2823 | 0.4642 |
| 2K | 0.0817 | 0.0728 | 0.0958 | 0.1545 | 0.2699 |
| 4K | 0.0675 | 0.0533 | 0.0604 | 0.0892 | 0.1567 |
| 8K | 0.0595 | 0.0431 | 0.0431 | 0.0560 | 0.0817 |
| 16K | 0.0545 | 0.0373 | 0.0338 | 0.0387 | 0.0498 |
| 32K | 0.0496 | 0.0326 | 0.0275 | 0.0277 | 0.0301 |
| 64K | 0.0432 | 0.0280 | 0.0232 | 0.0215 | 0.0206 |
| 128K | 0.0336 | 0.0217 | 0.0179 | 0.0158 | 0.0140 |
| 256K | 0.0207 | 0.0136 | 0.0116 | 0.0107 | 0.0093 |
| 512K | 0.0103 | 0.0068 | 0.0060 | 0.0060 | 0.0053 |
| 1M | 0.0031 | 0.0021 | 0.0018 | 0.0019 | 0.0017 |

*Unified*

| Size | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.0543 | 0.0577 | 0.0776 | 0.1938 | 0.2540 |
| 2K | 0.0387 | 0.0368 | 0.0420 | 0.0682 | 0.1223 |
| 4K | 0.0192 | 0.0178 | 0.0214 | 0.0353 | 0.0714 |
| 8K | 0.0148 | 0.0121 | 0.0132 | 0.0200 | 0.0412 |
| 16K | 0.0125 | 0.0094 | 0.0092 | 0.0122 | 0.0266 |
| 32K | 0.0109 | 0.0075 | 0.0067 | 0.0076 | 0.0102 |
| 64K | 0.0091 | 0.0061 | 0.0052 | 0.0053 | 0.0057 |
| 128K | 0.0070 | 0.0046 | 0.0038 | 0.0036 | 0.0036 |
| 256K | 0.0044 | 0.0029 | 0.0025 | 0.0024 | 0.0024 |
| 512K | 0.0022 | 0.0015 | 0.0014 | 0.0014 | 0.0014 |
| 1M | 0.0007 | 0.0005 | 0.0005 | 0.0005 | 0.0006 |

**Eqntott : Associativity 2**

*Instruction*

| Size | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 2K | 0 | 0 | 0 | 0 | 0 |
| 4K | 0 | 0 | 0 | 0 | 0 |
| 8K | 0 | 0 | 0 | 0 | 0 |
| 16K | 0 | 0 | 0 | 0 | 0 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0573 | 0.0394 | 0.0422 | 0.0610 | 0.1307 |
| 4K | 0.0550 | 0.0363 | 0.0303 | 0.0317 | 0.0554 |
| 8K | 0.0533 | 0.0346 | 0.0273 | 0.0241 | 0.0304 |
| 16K | 0.0513 | 0.0329 | 0.0257 | 0.0212 | 0.0179 |
| 32K | 0.0482 | 0.0306 | 0.0238 | 0.0196 | 0.0153 |
| 64K | 0.0425 | 0.0268 | 0.0210 | 0.0173 | 0.0132 |
| 128K | 0.0318 | 0.0204 | 0.0166 | 0.0142 | 0.0108 |
| 256K | 0.0172 | 0.0115 | 0.0104 | 0.0096 | 0.0077 |
| 512K | 0.0055 | 0.0037 | 0.0037 | 0.0041 | 0.0037 |
| 1M | 0.0014 | 0.0008 | 0.0007 | 0.0008 | 0.0008 |

*Unified*

| Size | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0155 | 0.0117 | 0.0139 | 0.0589 | 0.1061 |
| 4K | 0.0130 | 0.0090 | 0.0079 | 0.0101 | 0.0234 |
| 8K | 0.0110 | 0.0072 | 0.0058 | 0.0055 | 0.0092 |
| 16K | 0.0106 | 0.0068 | 0.0053 | 0.0045 | 0.0048 |
| 32K | 0.0099 | 0.0063 | 0.0049 | 0.0040 | 0.0037 |
| 64K | 0.0087 | 0.0055 | 0.0043 | 0.0035 | 0.0027 |
| 128K | 0.0065 | 0.0042 | 0.0034 | 0.0029 | 0.0022 |
| 256K | 0.0035 | 0.0024 | 0.0021 | 0.0020 | 0.0016 |
| 512K | 0.0011 | 0.0008 | 0.0008 | 0.0008 | 0.0008 |
| 1M | 0.0003 | 0.0002 | 0.0001 | 0.0002 | 0.0002 |

**Eqntott : Associativity 4**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0 | 0 | 0 | 0 | 0 |
| 8K | 0 | 0 | 0 | 0 | 0 |
| 16K | 0 | 0 | 0 | 0 | 0 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0543 | 0.0352 | 0.0277 | 0.0237 | 0.0373 |
| 8K | 0.0531 | 0.0342 | 0.0266 | 0.0215 | 0.0179 |
| 16K | 0.0513 | 0.0328 | 0.0254 | 0.0205 | 0.0157 |
| 32K | 0.0481 | 0.0305 | 0.0237 | 0.0193 | 0.0145 |
| 64K | 0.0425 | 0.0266 | 0.0208 | 0.0172 | 0.0131 |
| 128K | 0.0316 | 0.0203 | 0.0165 | 0.0139 | 0.0105 |
| 256K | 0.0141 | 0.0099 | 0.0097 | 0.0094 | 0.0075 |
| 512K | 0.0031 | 0.0022 | 0.0026 | 0.0032 | 0.0031 |
| 1M | 0.0010 | 0.0005 | 0.0003 | 0.0003 | 0.0004 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0112 | 0.0073 | 0.0058 | 0.0062 | 0.0159 |
| 8K | 0.0109 | 0.0070 | 0.0055 | 0.0045 | 0.0048 |
| 16K | 0.0105 | 0.0067 | 0.0052 | 0.0042 | 0.0033 |
| 32K | 0.0099 | 0.0062 | 0.0049 | 0.0039 | 0.0030 |
| 64K | 0.0087 | 0.0055 | 0.0043 | 0.0035 | 0.0027 |
| 128K | 0.0065 | 0.0041 | 0.0034 | 0.0028 | 0.0021 |
| 256K | 0.0029 | 0.0020 | 0.0020 | 0.0019 | 0.0015 |
| 512K | 0.0006 | 0.0005 | 0.0005 | 0.0007 | 0.0006 |
| 1M | 0.0002 | 0.0001 | 0 | 0 | 0 |

**Eqntott : Associativity 8**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0 | 0 | 0 | 0 | 0 |
| 16K | 0 | 0 | 0 | 0 | 0 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0530 | 0.0342 | 0.0265 | 0.0214 | 0.0164 |
| 16K | 0.0512 | 0.0328 | 0.0254 | 0.0205 | 0.0155 |
| 32K | 0.0481 | 0.0304 | 0.0237 | 0.0193 | 0.0145 |
| 64K | 0.0425 | 0.0266 | 0.0207 | 0.0171 | 0.0131 |
| 128K | 0.0317 | 0.0202 | 0.0164 | 0.0138 | 0.0104 |
| 256K | 0.0117 | 0.0088 | 0.0095 | 0.0094 | 0.0075 |
| 512K | 0.0017 | 0.0011 | 0.0012 | 0.0022 | 0.0027 |
| 1M | 0.0009 | 0.0005 | 0.0002 | 0.0001 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0109 | 0.0070 | 0.0054 | 0.0044 | 0.0038 |
| 16K | 0.0105 | 0.0067 | 0.0052 | 0.0042 | 0.0032 |
| 32K | 0.0099 | 0.0062 | 0.0049 | 0.0039 | 0.0030 |
| 64K | 0.0087 | 0.0054 | 0.0042 | 0.0035 | 0.0027 |
| 128K | 0.0065 | 0.0041 | 0.0034 | 0.0028 | 0.0021 |
| 256K | 0.0024 | 0.0018 | 0.0019 | 0.0019 | 0.0015 |
| 512K | 0.0004 | 0.0002 | 0.0003 | 0.0005 | 0.0006 |
| 1M | 0.0002 | 0 | 0 | 0 | 0 |

**Xlisp : Associativity 1**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1516 | 0.0985 | 0.0710 | 0.0575 | 0.0564 |
| 2K | 0.1007 | 0.0681 | 0.0492 | 0.0415 | 0.0410 |
| 4K | 0.0595 | 0.0415 | 0.0299 | 0.0237 | 0.0244 |
| 8K | 0.0293 | 0.0195 | 0.0144 | 0.0134 | 0.0146 |
| 16K | 0.0229 | 0.0149 | 0.0106 | 0.0098 | 0.0114 |
| 32K | 0.0049 | 0.0035 | 0.0024 | 0.0020 | 0.0018 |
| 64K | 0.0006 | 0.0004 | 0.0002 | 0.0002 | 0.0002 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1194 | 0.1170 | 0.1195 | 0.1336 | 0.1630 |
| 2K | 0.0784 | 0.0756 | 0.0772 | 0.0859 | 0.1036 |
| 4K | 0.0503 | 0.0447 | 0.0426 | 0.0472 | 0.0546 |
| 8K | 0.0274 | 0.0218 | 0.0200 | 0.0209 | 0.0243 |
| 16K | 0.0199 | 0.0143 | 0.0122 | 0.0130 | 0.0150 |
| 32K | 0.0164 | 0.0111 | 0.0083 | 0.0077 | 0.0081 |
| 64K | 0.0090 | 0.0053 | 0.0034 | 0.0029 | 0.0027 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.2015 | 0.1642 | 0.1506 | 0.1751 | 0.2434 |
| 2K | 0.1464 | 0.1206 | 0.1078 | 0.1187 | 0.1583 |
| 4K | 0.0895 | 0.0712 | 0.0609 | 0.0656 | 0.0871 |
| 8K | 0.0495 | 0.0399 | 0.0353 | 0.0402 | 0.0559 |
| 16K | 0.0282 | 0.0208 | 0.0175 | 0.0179 | 0.0233 |
| 32K | 0.0122 | 0.0093 | 0.0078 | 0.0074 | 0.0092 |
| 64K | 0.0049 | 0.0035 | 0.0029 | 0.0030 | 0.0043 |
| 128K | 0.0004 | 0.0003 | 0.0002 | 0.0002 | 0.0002 |
| 256K | 0.0004 | 0.0003 | 0.0002 | 0.0002 | 0.0002 |
| 512K | 0.0004 | 0.0003 | 0.0002 | 0.0002 | 0.0002 |
| 1M | 0.0004 | 0.0003 | 0.0002 | 0.0002 | 0.0002 |

**Xlisp : Associativity 2**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0843 | 0.0575 | 0.0422 | 0.0357 | 0.0359 |
| 4K | 0.0521 | 0.0371 | 0.0296 | 0.0249 | 0.0243 |
| 8K | 0.0166 | 0.0114 | 0.0103 | 0.0094 | 0.0095 |
| 16K | 0.0033 | 0.0029 | 0.0023 | 0.0024 | 0.0027 |
| 32K | 0.0027 | 0.0024 | 0.0019 | 0.0021 | 0.0021 |
| 64K | 0.0004 | 0.0004 | 0.0002 | 0.0002 | 0.0002 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0493 | 0.0447 | 0.0455 | 0.0516 | 0.0601 |
| 4K | 0.0318 | 0.0257 | 0.0233 | 0.0225 | 0.0270 |
| 8K | 0.0200 | 0.0144 | 0.0118 | 0.0099 | 0.0104 |
| 16K | 0.0134 | 0.0079 | 0.0051 | 0.0039 | 0.0035 |
| 32K | 0.0070 | 0.0041 | 0.0026 | 0.0020 | 0.0017 |
| 64K | 0.0032 | 0.0017 | 0.0009 | 0.0005 | 0.0003 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.1221 | 0.0934 | 0.0755 | 0.0676 | 0.0722 |
| 4K | 0.0726 | 0.0565 | 0.0482 | 0.0438 | 0.0455 |
| 8K | 0.0306 | 0.0240 | 0.0205 | 0.0189 | 0.0224 |
| 16K | 0.0113 | 0.0087 | 0.0072 | 0.0070 | 0.0087 |
| 32K | 0.0058 | 0.0042 | 0.0032 | 0.0031 | 0.0033 |
| 64K | 0.0020 | 0.0012 | 0.0008 | 0.0006 | 0.0006 |
| 128K | 0.0003 | 0.0002 | 0.0001 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

**Xlisp : Associativity 4**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0244 | 0.0199 | 0.0175 | 0.0175 | 0.0181 |
| 8K | 0.0091 | 0.0076 | 0.0076 | 0.0074 | 0.0085 |
| 16K | 0.0012 | 0.0013 | 0.0013 | 0.0015 | 0.0015 |
| 32K | 0 | 0 | 0 | 0.0001 | 0.0002 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0266 | 0.0187 | 0.0138 | 0.0136 | 0.0190 |
| 8K | 0.0169 | 0.0113 | 0.0084 | 0.0064 | 0.0057 |
| 16K | 0.0126 | 0.0067 | 0.0041 | 0.0027 | 0.0019 |
| 32K | 0.0067 | 0.0034 | 0.0018 | 0.0009 | 0.0005 |
| 64K | 0.0002 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0518 | 0.0440 | 0.0394 | 0.0361 | 0.0379 |
| 8K | 0.0233 | 0.0182 | 0.0167 | 0.0164 | 0.0218 |
| 16K | 0.0078 | 0.0058 | 0.0047 | 0.0044 | 0.0049 |
| 32K | 0.0035 | 0.0020 | 0.0014 | 0.0011 | 0.0011 |
| 64K | 0.0005 | 0.0003 | 0.0002 | 0.0002 | 0.0002 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

**Xlisp : Associativity 8**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0011 | 0.0014 | 0.0017 | 0.0030 | 0.0044 |
| 16K | 0 | 0 | 0.0002 | 0.0006 | 0.0008 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0159 | 0.0105 | 0.0076 | 0.0058 | 0.0045 |
| 16K | 0.0124 | 0.0066 | 0.0037 | 0.0023 | 0.0018 |
| 32K | 0.0069 | 0.0036 | 0.0020 | 0.0010 | 0.0005 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0153 | 0.0119 | 0.0115 | 0.0120 | 0.0167 |
| 16K | 0.0059 | 0.0044 | 0.0038 | 0.0036 | 0.0044 |
| 32K | 0.0034 | 0.0018 | 0.0012 | 0.0008 | 0.0008 |
| 64K | 0.0004 | 0.0002 | 0.0001 | 0.0001 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

**GNU C Compiler : Associativity 1**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1414 | 0.0919 | 0.0635 | 0.0465 | 0.0371 |
| 2K | 0.1182 | 0.0769 | 0.0530 | 0.0387 | 0.0295 |
| 4K | 0.0876 | 0.0580 | 0.0410 | 0.0304 | 0.0229 |
| 8K | 0.0605 | 0.0407 | 0.0297 | 0.0225 | 0.0173 |
| 16K | 0.0339 | 0.0230 | 0.0167 | 0.0132 | 0.0105 |
| 32K | 0.0210 | 0.0139 | 0.0101 | 0.0080 | 0.0063 |
| 64K | 0.0131 | 0.0087 | 0.0063 | 0.0048 | 0.0038 |
| 128K | 0.0063 | 0.0042 | 0.0030 | 0.0022 | 0.0018 |
| 256K | 0.0034 | 0.0022 | 0.0016 | 0.0012 | 0.0011 |
| 512K | 0.0013 | 0.0009 | 0.0007 | 0.0005 | 0.0004 |
| 1M | 0.0006 | 0.0004 | 0.0003 | 0.0002 | 0.0002 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1640 | 0.1646 | 0.1835 | 0.2276 | 0.2987 |
| 2K | 0.1190 | 0.1153 | 0.1237 | 0.1496 | 0.1979 |
| 4K | 0.0841 | 0.0771 | 0.0789 | 0.0907 | 0.1204 |
| 8K | 0.0547 | 0.0481 | 0.0472 | 0.0537 | 0.0707 |
| 16K | 0.0344 | 0.0289 | 0.0274 | 0.0294 | 0.0366 |
| 32K | 0.0218 | 0.0176 | 0.0159 | 0.0161 | 0.0198 |
| 64K | 0.0146 | 0.0114 | 0.0099 | 0.0093 | 0.0105 |
| 128K | 0.0089 | 0.0067 | 0.0056 | 0.0052 | 0.0058 |
| 256K | 0.0045 | 0.0032 | 0.0025 | 0.0022 | 0.0022 |
| 512K | 0.0029 | 0.0020 | 0.0016 | 0.0013 | 0.0013 |
| 1M | 0.0017 | 0.0010 | 0.0007 | 0.0006 | 0.0006 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.2235 | 0.1823 | 0.1783 | 0.2039 | 0.2692 |
| 2K | 0.1826 | 0.1434 | 0.1345 | 0.1437 | 0.1811 |
| 4K | 0.1422 | 0.1105 | 0.1021 | 0.1036 | 0.1210 |
| 8K | 0.1067 | 0.0829 | 0.0782 | 0.0782 | 0.0873 |
| 16K | 0.0518 | 0.0402 | 0.0341 | 0.0352 | 0.0421 |
| 32K | 0.0330 | 0.0254 | 0.0213 | 0.0228 | 0.0282 |
| 64K | 0.0218 | 0.0168 | 0.0142 | 0.0154 | 0.0194 |
| 128K | 0.0120 | 0.0092 | 0.0078 | 0.0086 | 0.0101 |
| 256K | 0.0063 | 0.0049 | 0.0042 | 0.0040 | 0.0043 |
| 512K | 0.0036 | 0.0030 | 0.0027 | 0.0028 | 0.0032 |
| 1M | 0.0023 | 0.0020 | 0.0019 | 0.0021 | 0.0025 |

**GNU C Compiler : Associativity 2**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.1083 | 0.0699 | 0.0486 | 0.0352 | 0.0272 |
| 4K | 0.0776 | 0.0520 | 0.0371 | 0.0273 | 0.0209 |
| 8K | 0.0441 | 0.0302 | 0.0230 | 0.0183 | 0.0145 |
| 16K | 0.0229 | 0.0159 | 0.0121 | 0.0099 | 0.0084 |
| 32K | 0.0123 | 0.0085 | 0.0061 | 0.0051 | 0.0043 |
| 64K | 0.0069 | 0.0046 | 0.0032 | 0.0025 | 0.0020 |
| 128K | 0.0036 | 0.0024 | 0.0017 | 0.0013 | 0.0010 |
| 256K | 0.0014 | 0.0010 | 0.0008 | 0.0006 | 0.0005 |
| 512K | 0.0006 | 0.0004 | 0.0003 | 0.0002 | 0.0002 |
| 1M | 0.0003 | 0.0002 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0867 | 0.0806 | 0.0824 | 0.0992 | 0.1473 |
| 4K | 0.0608 | 0.0533 | 0.0513 | 0.0575 | 0.0789 |
| 8K | 0.0424 | 0.0337 | 0.0305 | 0.0323 | 0.0408 |
| 16K | 0.0254 | 0.0194 | 0.0163 | 0.0160 | 0.0193 |
| 32K | 0.0159 | 0.0117 | 0.0090 | 0.0076 | 0.0079 |
| 64K | 0.0098 | 0.0070 | 0.0053 | 0.0041 | 0.0035 |
| 128K | 0.0057 | 0.0040 | 0.0030 | 0.0022 | 0.0018 |
| 256K | 0.0030 | 0.0020 | 0.0013 | 0.0010 | 0.0007 |
| 512K | 0.0018 | 0.0010 | 0.0006 | 0.0004 | 0.0003 |
| 1M | 0.0014 | 0.0007 | 0.0004 | 0.0002 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.1362 | 0.1010 | 0.0832 | 0.0813 | 0.0963 |
| 4K | 0.1015 | 0.0746 | 0.0599 | 0.0555 | 0.0603 |
| 8K | 0.0646 | 0.0483 | 0.0399 | 0.0371 | 0.0384 |
| 16K | 0.0369 | 0.0279 | 0.0233 | 0.0221 | 0.0235 |
| 32K | 0.0196 | 0.0146 | 0.0119 | 0.0114 | 0.0114 |
| 64K | 0.0112 | 0.0080 | 0.0062 | 0.0055 | 0.0055 |
| 128K | 0.0064 | 0.0044 | 0.0034 | 0.0028 | 0.0026 |
| 256K | 0.0031 | 0.0022 | 0.0016 | 0.0013 | 0.0011 |
| 512K | 0.0014 | 0.0009 | 0.0007 | 0.0005 | 0.0005 |
| 1M | 0.0007 | 0.0004 | 0.0003 | 0.0002 | 0.0002 |

| GNU C Compiler : Associativity 4 | | | | | |
|---|---|---|---|---|---|
| *Instruction* | | | | | |
| Size | Block size (bytes) | | | | |
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0717 | 0.0487 | 0.0350 | 0.0261 | 0.0200 |
| 8K | 0.0369 | 0.0261 | 0.0206 | 0.0170 | 0.0136 |
| 16K | 0.0171 | 0.0121 | 0.0094 | 0.0081 | 0.0072 |
| 32K | 0.0089 | 0.0060 | 0.0044 | 0.0036 | 0.0032 |
| 64K | 0.0054 | 0.0034 | 0.0024 | 0.0018 | 0.0015 |
| 128K | 0.0028 | 0.0020 | 0.0014 | 0.0011 | 0.0008 |
| 256K | 0.0009 | 0.0007 | 0.0005 | 0.0005 | 0.0004 |
| 512K | 0.0003 | 0.0002 | 0.0001 | 0 | 0 |
| 1M | 0.0003 | 0.0001 | 0 | 0 | 0 |
| *Data* | | | | | |
| Size | Block size (bytes) | | | | |
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0533 | 0.0437 | 0.0411 | 0.0461 | 0.0628 |
| 8K | 0.0389 | 0.0287 | 0.0243 | 0.0249 | 0.0326 |
| 16K | 0.0224 | 0.0167 | 0.0137 | 0.0129 | 0.0149 |
| 32K | 0.0145 | 0.0103 | 0.0076 | 0.0059 | 0.0054 |
| 64K | 0.0091 | 0.0064 | 0.0047 | 0.0034 | 0.0026 |
| 128K | 0.0050 | 0.0034 | 0.0025 | 0.0018 | 0.0013 |
| 256K | 0.0026 | 0.0016 | 0.0011 | 0.0008 | 0.0005 |
| 512K | 0.0016 | 0.0009 | 0.0006 | 0.0004 | 0.0002 |
| 1M | 0.0013 | 0.0007 | 0.0003 | 0.0002 | 0 |
| *Unified* | | | | | |
| Size | Block size (bytes) | | | | |
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0942 | 0.0686 | 0.0540 | 0.0467 | 0.0478 |
| 8K | 0.0577 | 0.0436 | 0.0357 | 0.0315 | 0.0302 |
| 16K | 0.0301 | 0.0228 | 0.0190 | 0.0179 | 0.0180 |
| 32K | 0.0154 | 0.0114 | 0.0091 | 0.0082 | 0.0084 |
| 64K | 0.0088 | 0.0061 | 0.0046 | 0.0038 | 0.0036 |
| 128K | 0.0053 | 0.0036 | 0.0026 | 0.0020 | 0.0016 |
| 256K | 0.0024 | 0.0017 | 0.0012 | 0.0010 | 0.0008 |
| 512K | 0.0010 | 0.0006 | 0.0004 | 0.0004 | 0.0003 |
| 1M | 0.0006 | 0.0003 | 0.0002 | 0 | 0 |

| GNU C Compiler : Associativity 8 | | | | | |
|---|---|---|---|---|---|
| *Instruction* | | | | | |
| Size | Block size (bytes) | | | | |
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0323 | 0.0241 | 0.0197 | 0.0167 | 0.0136 |
| 16K | 0.0144 | 0.0101 | 0.0079 | 0.0071 | 0.0066 |
| 32K | 0.0081 | 0.0054 | 0.0039 | 0.0030 | 0.0027 |
| 64K | 0.0051 | 0.0032 | 0.0022 | 0.0016 | 0.0013 |
| 128K | 0.0026 | 0.0019 | 0.0014 | 0.0010 | 0.0007 |
| 256K | 0.0005 | 0.0003 | 0.0004 | 0.0004 | 0.0004 |
| 512K | 0.0003 | 0.0001 | 0 | 0 | 0 |
| 1M | 0.0003 | 0.0001 | 0 | 0 | 0 |
| *Data* | | | | | |
| Size | Block size (bytes) | | | | |
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0375 | 0.0270 | 0.0223 | 0.0224 | 0.0303 |
| 16K | 0.0214 | 0.0155 | 0.0122 | 0.0107 | 0.0120 |
| 32K | 0.0121 | 0.0087 | 0.0066 | 0.0051 | 0.0045 |
| 64K | 0.0087 | 0.0062 | 0.0046 | 0.0033 | 0.0023 |
| 128K | 0.0048 | 0.0032 | 0.0024 | 0.0017 | 0.0012 |
| 256K | 0.0025 | 0.0016 | 0.0010 | 0.0007 | 0.0005 |
| 512K | 0.0016 | 0.0009 | 0.0005 | 0.0003 | 0.0002 |
| 1M | 0.0013 | 0.0007 | 0.0003 | 0.0002 | 0 |
| *Unified* | | | | | |
| Size | Block size (bytes) | | | | |
| (bytes) | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0532 | 0.0411 | 0.0345 | 0.0307 | 0.0290 |
| 16K | 0.0272 | 0.0203 | 0.0172 | 0.0168 | 0.0172 |
| 32K | 0.0135 | 0.0099 | 0.0079 | 0.0071 | 0.0073 |
| 64K | 0.0081 | 0.0055 | 0.0041 | 0.0033 | 0.0029 |
| 128K | 0.0050 | 0.0033 | 0.0023 | 0.0017 | 0.0014 |
| 256K | 0.0019 | 0.0014 | 0.0011 | 0.0009 | 0.0007 |
| 512K | 0.0008 | 0.0005 | 0.0003 | 0.0003 | 0.0002 |
| 1M | 0.0006 | 0.0003 | 0.0002 | 0 | 0 |

**Espresso : Associativity 1**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.0323 | 0.0195 | 0.0121 | 0.0105 | 0.0135 |
| 2K | 0.0242 | 0.0146 | 0.0090 | 0.0081 | 0.0065 |
| 4K | 0.0181 | 0.0109 | 0.0068 | 0.0066 | 0.0054 |
| 8K | 0.0083 | 0.0050 | 0.0032 | 0.0025 | 0.0021 |
| 16K | 0.0053 | 0.0033 | 0.0021 | 0.0016 | 0.0014 |
| 32K | 0.0034 | 0.0021 | 0.0013 | 0.0012 | 0.0010 |
| 64K | 0.0031 | 0.0019 | 0.0012 | 0.0011 | 0.0009 |
| 128K | 0.0030 | 0.0019 | 0.0012 | 0.0010 | 0.0009 |
| 256K | 0.0029 | 0.0018 | 0.0012 | 0.0010 | 0.0008 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1591 | 0.1405 | 0.1724 | 0.2256 | 0.3287 |
| 2K | 0.1219 | 0.0948 | 0.1079 | 0.1326 | 0.1890 |
| 4K | 0.0989 | 0.0722 | 0.0742 | 0.0845 | 0.1106 |
| 8K | 0.0764 | 0.0541 | 0.0546 | 0.0596 | 0.0737 |
| 16K | 0.0576 | 0.0383 | 0.0384 | 0.0375 | 0.0412 |
| 32K | 0.0268 | 0.0183 | 0.0114 | 0.0095 | 0.0108 |
| 64K | 0.0095 | 0.0064 | 0.0045 | 0.0047 | 0.0062 |
| 128K | 0.0043 | 0.0030 | 0.0018 | 0.0014 | 0.0015 |
| 256K | 0.0001 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 1K | 0.1229 | 0.1143 | 0.1250 | 0.1490 | 0.2128 |
| 2K | 0.0832 | 0.0684 | 0.0705 | 0.0834 | 0.1209 |
| 4K | 0.0511 | 0.0387 | 0.0374 | 0.0449 | 0.0628 |
| 8K | 0.0328 | 0.0239 | 0.0228 | 0.0248 | 0.0371 |
| 16K | 0.0239 | 0.0168 | 0.0158 | 0.0163 | 0.0240 |
| 32K | 0.0137 | 0.0097 | 0.0075 | 0.0074 | 0.0108 |
| 64K | 0.0063 | 0.0043 | 0.0032 | 0.0034 | 0.0052 |
| 128K | 0.0044 | 0.0028 | 0.0019 | 0.0017 | 0.0018 |
| 256K | 0.0026 | 0.0016 | 0.0011 | 0.0010 | 0.0008 |
| 512K | 0.0003 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |
| 1M | 0.0003 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |

**Espresso : Associativity 2**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0173 | 0.0105 | 0.0065 | 0.0048 | 0.0038 |
| 4K | 0.0101 | 0.0062 | 0.0040 | 0.0033 | 0.0028 |
| 8K | 0.0034 | 0.0023 | 0.0015 | 0.0014 | 0.0015 |
| 16K | 0.0014 | 0.0011 | 0.0007 | 0.0007 | 0.0006 |
| 32K | 0.0005 | 0.0004 | 0.0003 | 0.0003 | 0.0003 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0993 | 0.0637 | 0.0532 | 0.0636 | 0.0998 |
| 4K | 0.0821 | 0.0488 | 0.0351 | 0.0317 | 0.0398 |
| 8K | 0.0606 | 0.0350 | 0.0217 | 0.0171 | 0.0200 |
| 16K | 0.0383 | 0.0225 | 0.0129 | 0.0095 | 0.0118 |
| 32K | 0.0249 | 0.0178 | 0.0094 | 0.0053 | 0.0035 |
| 64K | 0.0028 | 0.0020 | 0.0011 | 0.0007 | 0.0005 |
| 128K | 0.0003 | 0.0001 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 2K | 0.0483 | 0.0344 | 0.0312 | 0.0375 | 0.0612 |
| 4K | 0.0342 | 0.0217 | 0.0164 | 0.0167 | 0.0228 |
| 8K | 0.0228 | 0.0143 | 0.0097 | 0.0091 | 0.0105 |
| 16K | 0.0140 | 0.0088 | 0.0059 | 0.0050 | 0.0054 |
| 32K | 0.0087 | 0.0061 | 0.0038 | 0.0028 | 0.0026 |
| 64K | 0.0020 | 0.0014 | 0.0009 | 0.0007 | 0.0006 |
| 128K | 0.0003 | 0.0002 | 0.0002 | 0.0001 | 0.0001 |
| 256K | 0.0002 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

**Espresso : Associativity 4**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0092 | 0.0059 | 0.0038 | 0.0032 | 0.0025 |
| 8K | 0.0017 | 0.0012 | 0.0008 | 0.0006 | 0.0010 |
| 16K | 0.0002 | 0.0001 | 0 | 0 | 0.0001 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0792 | 0.0460 | 0.0280 | 0.0208 | 0.0214 |
| 8K | 0.0608 | 0.0344 | 0.0191 | 0.0117 | 0.0092 |
| 16K | 0.0332 | 0.0194 | 0.0105 | 0.0061 | 0.0039 |
| 32K | 0.0257 | 0.0158 | 0.0081 | 0.0042 | 0.0023 |
| 64K | 0.0026 | 0.0024 | 0.0012 | 0.0007 | 0.0004 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 4K | 0.0325 | 0.0201 | 0.0131 | 0.0109 | 0.0131 |
| 8K | 0.0210 | 0.0127 | 0.0079 | 0.0060 | 0.0056 |
| 16K | 0.0107 | 0.0065 | 0.0039 | 0.0028 | 0.0026 |
| 32K | 0.0070 | 0.0043 | 0.0023 | 0.0014 | 0.0011 |
| 64K | 0.0011 | 0.0009 | 0.0005 | 0.0004 | 0.0003 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

**Espresso : Associativity 8**

*Instruction*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0012 | 0.0008 | 0.0005 | 0.0005 | 0.0011 |
| 16K | 0.0001 | 0 | 0 | 0 | 0 |
| 32K | 0 | 0 | 0 | 0 | 0 |
| 64K | 0 | 0 | 0 | 0 | 0 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Data*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0616 | 0.0345 | 0.0186 | 0.0108 | 0.0080 |
| 16K | 0.0320 | 0.0187 | 0.0100 | 0.0056 | 0.0034 |
| 32K | 0.0264 | 0.0155 | 0.0079 | 0.0040 | 0.0022 |
| 64K | 0.0029 | 0.0030 | 0.0015 | 0.0008 | 0.0004 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |

*Unified*

| Size (bytes) | Block size (bytes) | | | | |
|---|---|---|---|---|---|
| | 16 | 32 | 64 | 128 | 256 |
| 8K | 0.0202 | 0.0123 | 0.0076 | 0.0058 | 0.0050 |
| 16K | 0.0099 | 0.0059 | 0.0034 | 0.0023 | 0.0020 |
| 32K | 0.0064 | 0.0038 | 0.0020 | 0.0011 | 0.0007 |
| 64K | 0.0008 | 0.0007 | 0.0004 | 0.0002 | 0.0001 |
| 128K | 0 | 0 | 0 | 0 | 0 |
| 256K | 0 | 0 | 0 | 0 | 0 |
| 512K | 0 | 0 | 0 | 0 | 0 |
| 1M | 0 | 0 | 0 | 0 | 0 |