Project Report Title

Course Name: EG-212, Computer Architecture: Memory Design
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September 6, 2024

1 Introduction

1.1 Objective

The objective of this project is to evaluate how different cache parameters-specifically cache size, block size, and associativity affect the cache hit and miss rates. The cache model uses a 4-way set associative design, and the results are obtained using given memory trace files.

2 Methodology

2.1 Cache Structure

Each cache consists of multiple sets, each containing a number of cache lines. The associativity determines how many cache lines are present per set. We use the Least Recently Used (LRU) replacement policy to manage cache line eviction when necessary.

2.2 Simulation Procedure

Address Handling: Each memory address from the trace files is 32 bits long. It is split into a tag, set index, and block offset. The cache accesses the corresponding set and searches for a matching tag within the set to determine whether it's a cache hit or miss.
Replacement: On a miss, the cache replaces the least recently used line in the set with the new block.

3 Results

3.1 Cache Size: 1024KB

Following is the code output:

```
For Cache Size = 1024 KB, Block Size = 4 Bytes, Associativity = 4:
gcc.trace: Hit Rate = 93.83555401283347%, Hits = 483894, Misses = 31789, Total Accesses = 515683
gzip.trace: Hit Rate = 66.70554044952229%, Hits = 320883, Misses = 160161, Total Accesses = 481044
swim.trace: Hit Rate = 92.62252096849201%, Hits = 280825, Misses = 22368, Total Accesses = 303193
twolf.trace: Hit Rate = 98.76145344887578%, Hits = 476844, Misses = 5980, Total Accesses = 482824
mcf.trace: Hit Rate = 1.03241065412593%, Hits = 7508, Misses = 719722, Total Accesses = 727230
```

3.2 Varying Cache Sizes: (Cache Size: 128KB to 4096KB)

Following is the code output and the graph:

```
For Varying Cache Size:

gcc.trace:
Cache Size = 128 KB, Hit Rate = 93.80%, Hits = 483719, Misses = 31964, Total Accesses = 515683
Cache Size = 256 KB, Hit Rate = 93.83%, Hits = 483871, Misses = 31812, Total Accesses = 515683
Cache Size = 512 KB, Hit Rate = 93.84%, Hits = 483893, Misses = 31790, Total Accesses = 515683
Cache Size = 1024 KB, Hit Rate = 93.84%, Hits = 483894, Misses = 31789, Total Accesses = 515683
Cache Size = 2048 KB, Hit Rate = 93.84%, Hits = 483894, Misses = 31789, Total Accesses = 515683
Cache Size = 4096 KB, Hit Rate = 93.84%, Hits = 483894, Misses = 31789, Total Accesses = 515683

gzip.trace:
Cache Size = 128 KB, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Cache Size = 256 KB, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Cache Size = 512 KB, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Cache Size = 1024 KB, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Cache Size = 2048 KB, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Cache Size = 4096 KB, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044

swim.trace:
Cache Size = 128 KB, Hit Rate = 92.62%, Hits = 280817, Misses = 22376, Total Accesses = 303193
Cache Size = 256 KB, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Cache Size = 512 KB, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Cache Size = 1024 KB, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Cache Size = 2048 KB, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Cache Size = 4096 KB, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193

twolf.trace:
Cache Size = 128 KB, Hit Rate = 98.76%, Hits = 476843, Misses = 5981, Total Accesses = 482824
Cache Size = 256 KB, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Cache Size = 512 KB, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Cache Size = 1024 KB, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Cache Size = 2048 KB, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Cache Size = 4096 KB, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824

mcf.trace:
Cache Size = 128 KB, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Cache Size = 256 KB, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Cache Size = 512 KB, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Cache Size = 1024 KB, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Cache Size = 2048 KB, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Cache Size = 4096 KB, Hit Rate = 1.05%, Hits = 7603, Misses = 719627, Total Accesses = 727230
```
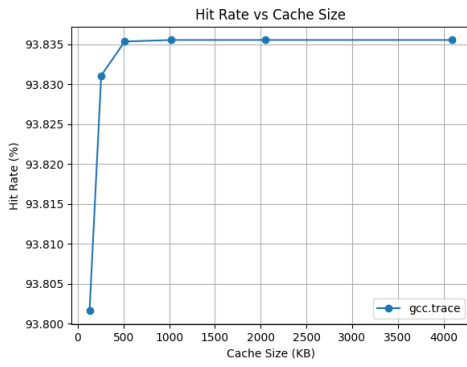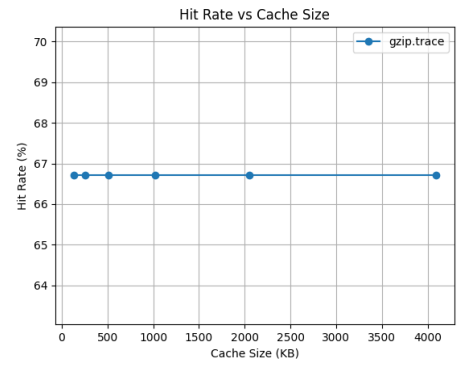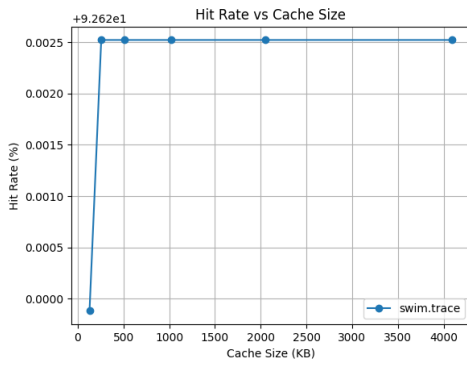
Figure 1: gcc.trace
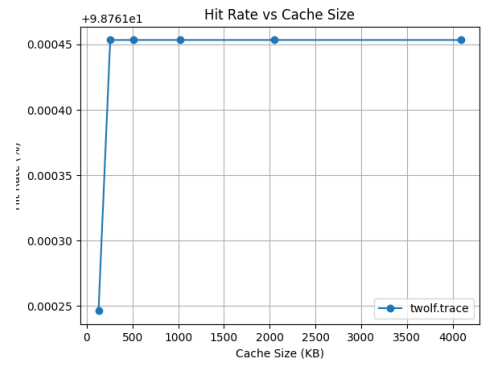

Figure 2: gzip.trace
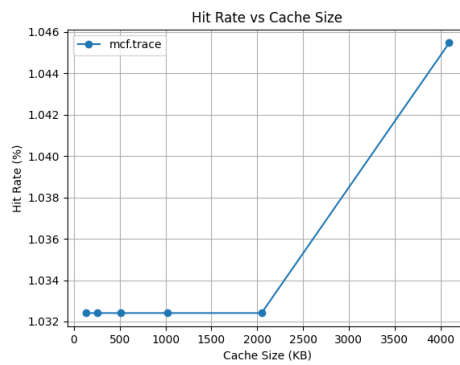

Figure 3: swim.trace

Figure 4: twolf.trace

Figure 5: mcf.trace

3.3 Varying Block Sizes: (Block Size: 1B to 128B)

Following is the code output and graph obtained:

```
For Varying Block Size:

gcc.trace:
Block Size = 1 Bytes, Hit Rate = 93.20%, Hits = 480611, Misses = 35072, Total Accesses = 515683
Block Size = 2 Bytes, Hit Rate = 93.62%, Hits = 482807, Misses = 32876, Total Accesses = 515683
Block Size = 4 Bytes, Hit Rate = 93.84%, Hits = 483894, Misses = 31789, Total Accesses = 515683
Block Size = 8 Bytes, Hit Rate = 95.93%, Hits = 494677, Misses = 21006, Total Accesses = 515683
Block Size = 16 Bytes, Hit Rate = 97.83%, Hits = 504467, Misses = 11216, Total Accesses = 515683
Block Size = 32 Bytes, Hit Rate = 98.83%, Hits = 509644, Misses = 6039, Total Accesses = 515683
Block Size = 64 Bytes, Hit Rate = 99.35%, Hits = 512310, Misses = 3373, Total Accesses = 515683
Block Size = 128 Bytes, Hit Rate = 99.62%, Hits = 513728, Misses = 1955, Total Accesses = 515683

gzip.trace:
Block Size = 1 Bytes, Hit Rate = 66.70%, Hits = 320875, Misses = 160169, Total Accesses = 481044
Block Size = 2 Bytes, Hit Rate = 66.70%, Hits = 320876, Misses = 160168, Total Accesses = 481044
Block Size = 4 Bytes, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Block Size = 8 Bytes, Hit Rate = 66.71%, Hits = 320891, Misses = 160153, Total Accesses = 481044
Block Size = 16 Bytes, Hit Rate = 66.79%, Hits = 321268, Misses = 159776, Total Accesses = 481044
Block Size = 32 Bytes, Hit Rate = 66.83%, Hits = 321459, Misses = 159585, Total Accesses = 481044
Block Size = 64 Bytes, Hit Rate = 66.85%, Hits = 321559, Misses = 159485, Total Accesses = 481044
Block Size = 128 Bytes, Hit Rate = 66.86%, Hits = 321609, Misses = 159435, Total Accesses = 481044

swim.trace:
Block Size = 1 Bytes, Hit Rate = 92.54%, Hits = 280588, Misses = 22605, Total Accesses = 303193
Block Size = 2 Bytes, Hit Rate = 92.59%, Hits = 280737, Misses = 22456, Total Accesses = 303193
Block Size = 4 Bytes, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Block Size = 8 Bytes, Hit Rate = 93.46%, Hits = 283377, Misses = 19816, Total Accesses = 303193
Block Size = 16 Bytes, Hit Rate = 96.23%, Hits = 291770, Misses = 11423, Total Accesses = 303193
Block Size = 32 Bytes, Hit Rate = 97.89%, Hits = 296797, Misses = 6396, Total Accesses = 303193
Block Size = 64 Bytes, Hit Rate = 98.86%, Hits = 299740, Misses = 3453, Total Accesses = 303193
Block Size = 128 Bytes, Hit Rate = 99.40%, Hits = 301367, Misses = 1826, Total Accesses = 303193

twolf.trace:
Block Size = 1 Bytes, Hit Rate = 98.48%, Hits = 475470, Misses = 7354, Total Accesses = 482824
Block Size = 2 Bytes, Hit Rate = 98.66%, Hits = 476358, Misses = 6466, Total Accesses = 482824
Block Size = 4 Bytes, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Block Size = 8 Bytes, Hit Rate = 98.86%, Hits = 477319, Misses = 5505, Total Accesses = 482824
Block Size = 16 Bytes, Hit Rate = 99.39%, Hits = 479869, Misses = 2955, Total Accesses = 482824
Block Size = 32 Bytes, Hit Rate = 99.66%, Hits = 481182, Misses = 1642, Total Accesses = 482824
Block Size = 64 Bytes, Hit Rate = 99.80%, Hits = 481870, Misses = 954, Total Accesses = 482824
Block Size = 128 Bytes, Hit Rate = 99.88%, Hits = 482249, Misses = 575, Total Accesses = 482824

mcf.trace:
Block Size = 1 Bytes, Hit Rate = 1.02%, Hits = 7451, Misses = 719779, Total Accesses = 727230
Block Size = 2 Bytes, Hit Rate = 1.03%, Hits = 7481, Misses = 719749, Total Accesses = 727230
Block Size = 4 Bytes, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Block Size = 8 Bytes, Hit Rate = 1.04%, Hits = 7551, Misses = 719679, Total Accesses = 727230
Block Size = 16 Bytes, Hit Rate = 50.50%, Hits = 367273, Misses = 359957, Total Accesses = 727230
Block Size = 32 Bytes, Hit Rate = 75.24%, Hits = 547152, Misses = 180078, Total Accesses = 727230
Block Size = 64 Bytes, Hit Rate = 87.61%, Hits = 637112, Misses = 90118, Total Accesses = 727230
Block Size = 128 Bytes, Hit Rate = 93.80%, Hits = 682109, Misses = 45121, Total Accesses = 727230
```
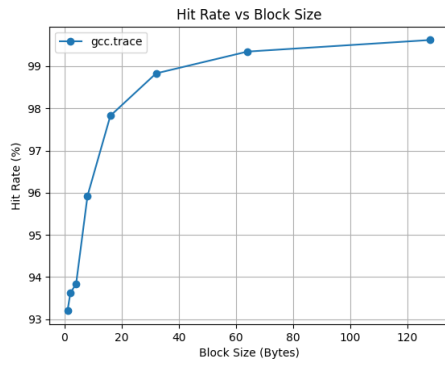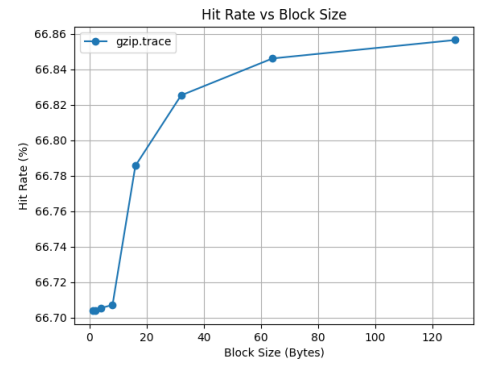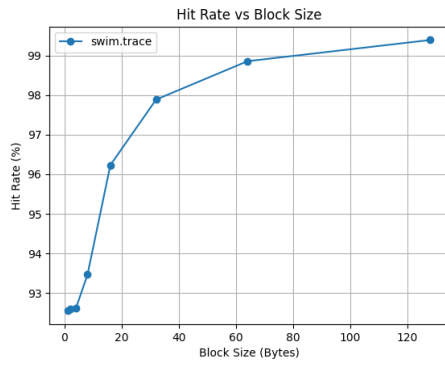
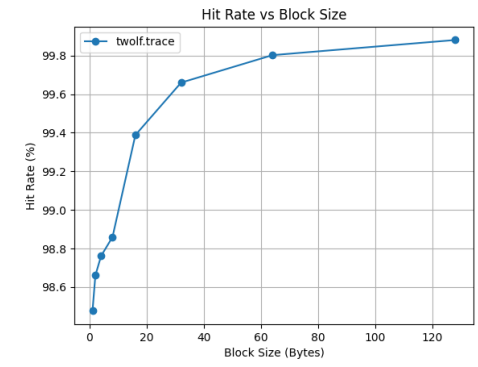Figure 6: gcc.trace

Figure 7: gzip.trace
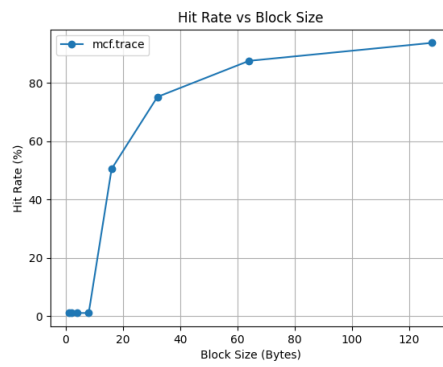

Figure 8: swim.trace

Figure 9: twolf.trace

Figure 10: mcf.trace

3.4 Varying Associativity: (Associativity: 1 to 64)

Following is the code output and graphs:

```
For Varying Associativity:

gcc.trace:
Associativity = 1, Hit Rate = 93.83%, Hits = 483868, Misses = 31815, Total Accesses = 515683
Associativity = 2, Hit Rate = 93.83%, Hits = 483890, Misses = 31793, Total Accesses = 515683
Associativity = 4, Hit Rate = 93.84%, Hits = 483894, Misses = 31789, Total Accesses = 515683
Associativity = 8, Hit Rate = 93.84%, Hits = 483894, Misses = 31789, Total Accesses = 515683
Associativity = 16, Hit Rate = 93.84%, Hits = 483895, Misses = 31788, Total Accesses = 515683
Associativity = 32, Hit Rate = 93.84%, Hits = 483896, Misses = 31787, Total Accesses = 515683
Associativity = 64, Hit Rate = 93.84%, Hits = 483896, Misses = 31787, Total Accesses = 515683

gzip.trace:
Associativity = 1, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Associativity = 2, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Associativity = 4, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Associativity = 8, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Associativity = 16, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Associativity = 32, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044
Associativity = 64, Hit Rate = 66.71%, Hits = 320883, Misses = 160161, Total Accesses = 481044

swim.trace:
Associativity = 1, Hit Rate = 92.62%, Hits = 280819, Misses = 22374, Total Accesses = 303193
Associativity = 2, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Associativity = 4, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Associativity = 8, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Associativity = 16, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Associativity = 32, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193
Associativity = 64, Hit Rate = 92.62%, Hits = 280825, Misses = 22368, Total Accesses = 303193

twolf.trace:
Associativity = 1, Hit Rate = 98.75%, Hits = 476771, Misses = 6053, Total Accesses = 482824
Associativity = 2, Hit Rate = 98.76%, Hits = 476841, Misses = 5983, Total Accesses = 482824
Associativity = 4, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Associativity = 8, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Associativity = 16, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Associativity = 32, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824
Associativity = 64, Hit Rate = 98.76%, Hits = 476844, Misses = 5980, Total Accesses = 482824

mcf.trace:
Associativity = 1, Hit Rate = 1.03%, Hits = 7505, Misses = 719725, Total Accesses = 727230
Associativity = 2, Hit Rate = 1.03%, Hits = 7507, Misses = 719723, Total Accesses = 727230
Associativity = 4, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Associativity = 8, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Associativity = 16, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Associativity = 32, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
Associativity = 64, Hit Rate = 1.03%, Hits = 7508, Misses = 719722, Total Accesses = 727230
```
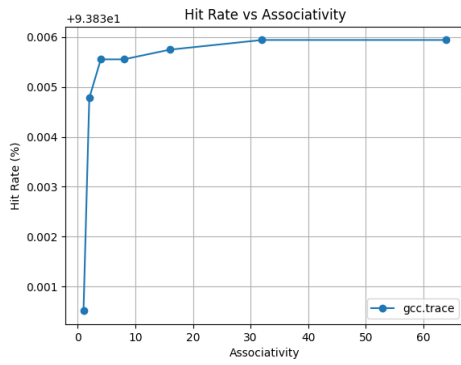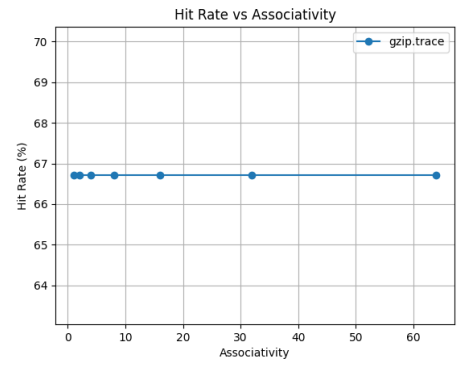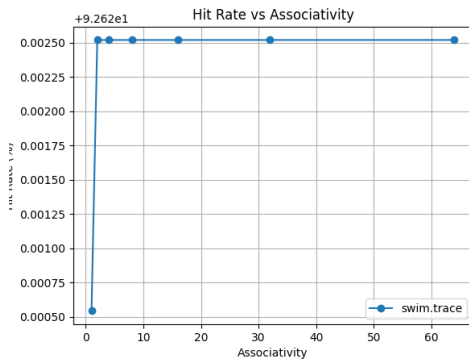
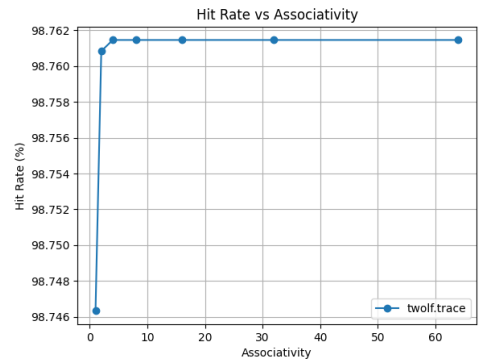Figure 11: gcc.trace

Figure 12: gzip.trace
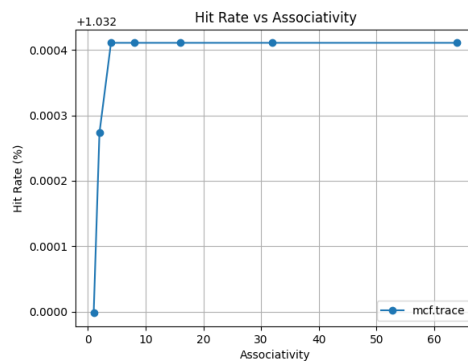

Figure 13: swim.trace

Figure 14: twolf.trace

Figure 15: mcf.trace

4 Observations

4.1 Cache Size Impact

gcc.trace: Minimal impact; hit rate stabilizes around 93.84%, indicating sufficient cache size at 512 KB.
gzip.trace: No improvement; hit rate remains at 66.71%, suggesting large working set or poor fit with cache.
swim.trace: Stable hit rate at 92.62%, indicating 128 KB cache is adequate.
twolf.trace: Consistent hit rate at 98.76%, showing large caches are unnecessary.
mcf.trace: Slight improvement; hit rate rises from 1.03% to 1.05% with larger cache sizes.

4.2 Block Size Impact

gcc.trace: Hit rate increases from 93.20% to 99.62% with larger block sizes, showing improved performance with larger blocks.
gzip.trace: Hit rate improves slightly, from 66.70% to 66.86%, indicating that larger blocks capture more locality but with marginal gains.
swim.trace: Significant increase from 92.54% to 99.40%, demonstrating the effectiveness of larger blocks for high spatial locality.
twolf.trace: Hit rate improves from 98.48% to 99.88%, showing that larger blocks are effective.
mcf.trace: Increase from 1.02% to 93.80%, highlighting the substantial benefit of larger blocks.

4.3 Associativity Impact

For all the traces, no significant change in hit rates with varying associativity. This suggests that increasing associativity beyond a certain point does not provide additional benefits for these traces. The hit rate remains almost constant despite increasing associativity, indicating that the hit rate is more influenced by other factors, such as block size or cache size, rather than associativity.

5 Conclusion

Cache Size: For traces with stable hit rates (e.g., gzip, swim, twolf), increasing the cache size does not offer substantial improvements. For traces with low hit rates (e.g., mcf), larger caches provide only marginal improvements.
Block Size: Larger block sizes generally improve hit rates across all traces. This improvement is more pronounced in traces with high spatial locality (swim, twolf, mcf).
Associativity: Increasing associativity does not significantly affect the hit rate for most traces, suggesting that other factors (such as cache size and block size) are more influential in these cases.

6 Project Implementation

Here is the link to github repository:

`https://github.com/Harsh-Mohta9163/CA-Assignment`