Computer Architecture Assignment-2

Course Name: EGC 223, Computer Architecture Memory Design

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1 Introduction

- In this assignment we are building a set associative cache. We have four parts included in this assignment.
- In our code, we have implemented a cache simulation using object oriented approach in python. We have made various classes.
- The BlockLine class represents a block in the cache which tracks last access time to implement LRU policy, valid bit and tag.
- The EachSet class represents a line or set in the cache. It contains a list of BlockLine objects. We have implemented methods get $_lru\_indexandeach\_block\_accesstodeterminetheleastrecentlyusedblockandforupdating\ access\ ti$
- The code initializes several trace files and loads them into memory.
- The user selects a part of the program to execute and the code includes a check for invalid user input, ensuring the user selects an appropriate part ('a', 'b', 'c', or 'd').
- Part a : We designed a 4-way set associative cache of size 1024kilobytes, Block size: 4 bytes.

  Part b: In this part we are changing the cache size from 128kB to 4096 kB.

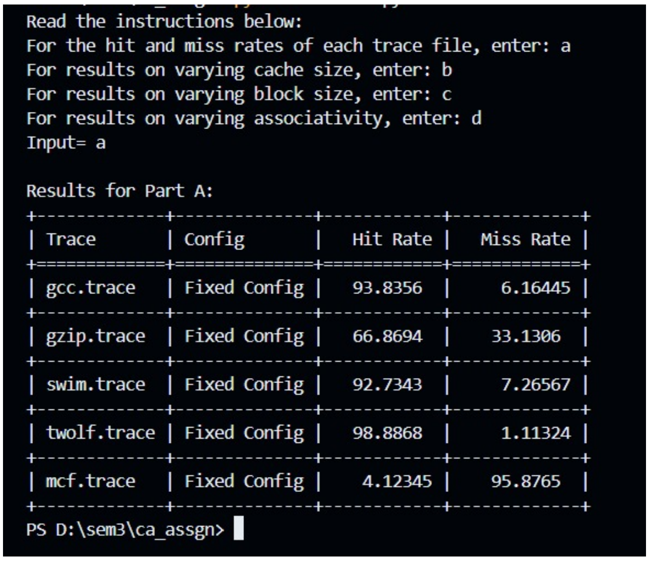
  Part c: Here we are changing the block size from 1 byte to 128 bytes.

  Part d: We are changing the number of ways from 1 way to 64 ways.
- Note: all the changes in the number of cache sizes, block sizes and associativities are done in powers of 2 between the provided ranges.
- We find miss and hit rates for each trace file while varying the parameters specified. We plot the graphs and tables as mentioned in the problem statement.

2 Parts

2.1 a) 4-way Set-Associative cache

- We are given a cache size of 1024 kilobytes and block size of 4 bytes
- Number of bytes in one cacheLine= block size * number of ways=4*4=16 bytes
- number of cache lines= cache size(in bytes)/number of bytes in one cache line=1024 *1024/16=65,536



```
Read the instructions below:
For the hit and miss rates of each trace file, enter: a
For results on varying cache size, enter: b
For results on varying block size, enter: c
For results on varying associativity, enter: d
Input= a

Results for Part A:
+------------+-------------+-----------+------------+
| Trace      | Config      |  Hit Rate |  Miss Rate |
+============+=============+===========+============+
| gcc.trace  | Fixed Config |  93.8356  |    6.16445 |
+------------+-------------+-----------+------------+
| gzip.trace | Fixed Config |  66.8694  |   33.1306  |
+------------+-------------+-----------+------------+
| swim.trace | Fixed Config |  92.7343  |    7.26567 |
+------------+-------------+-----------+------------+
| twolf.trace | Fixed Config |  98.8868  |    1.11324 |
+------------+-------------+-----------+------------+
| mcf.trace  | Fixed Config |   4.12345 |   95.8765  |
+------------+-------------+-----------+------------+
PS D:\sem3\ca_assgn> █
```

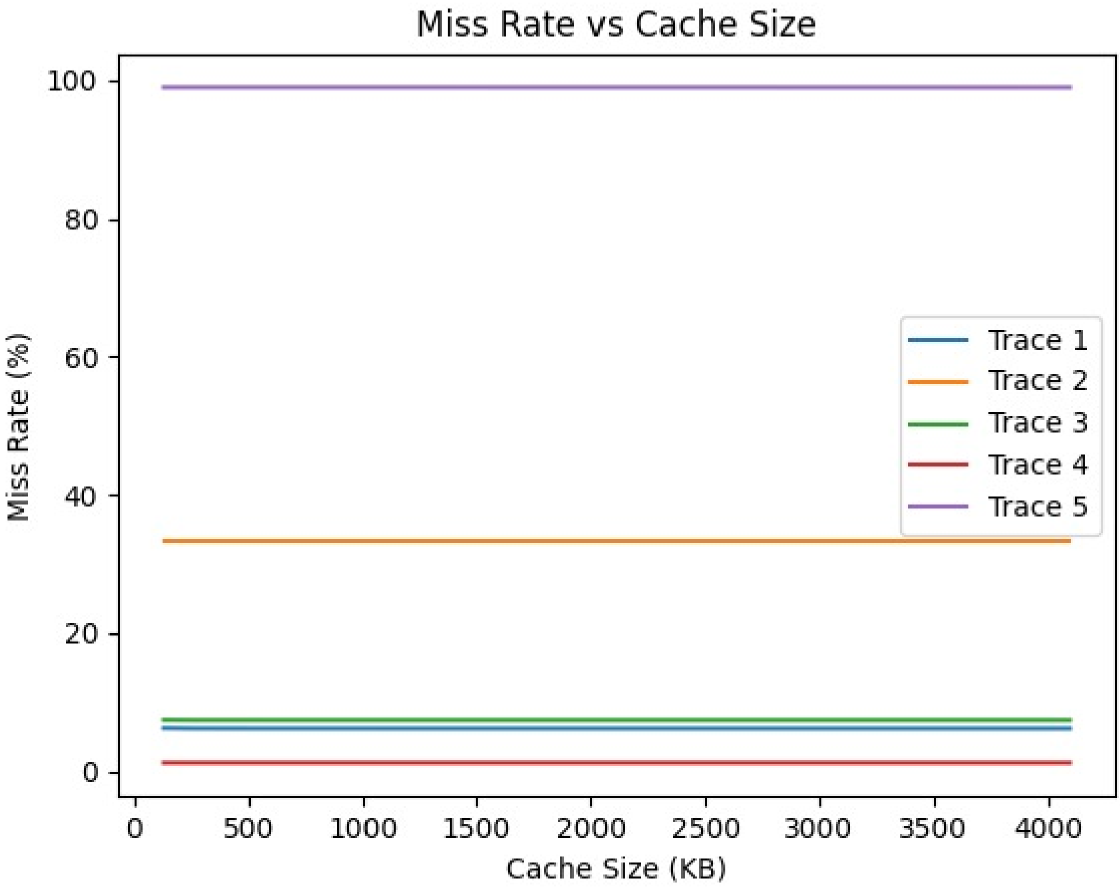
Observations:

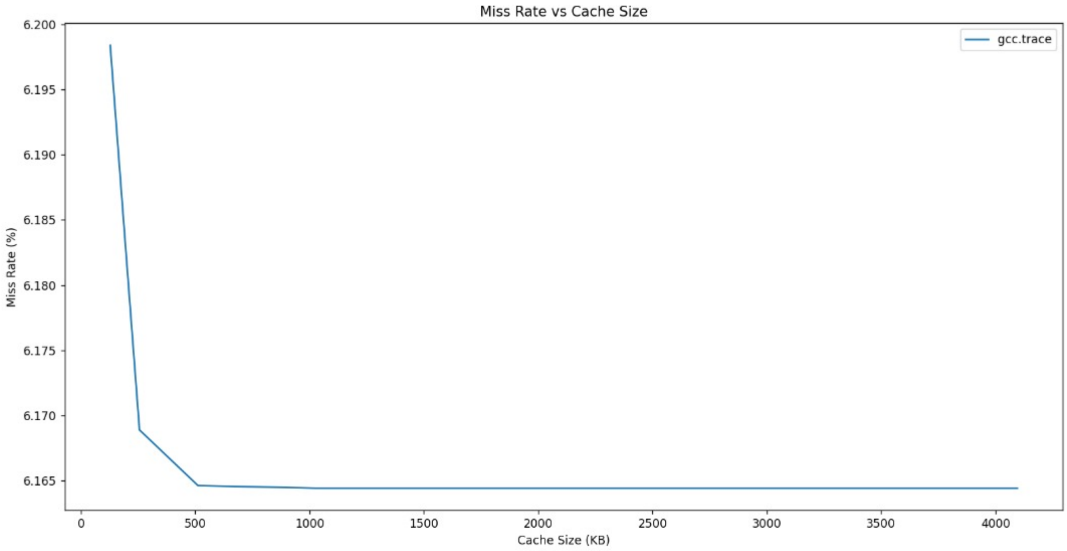
- **The above table shows the hit and miss rates of each trace file.**

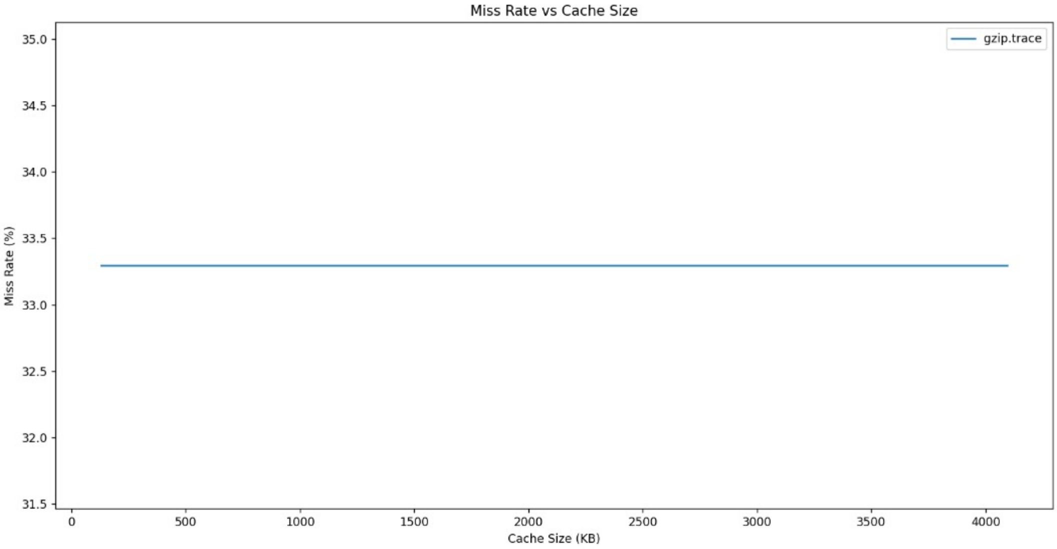
- **Descending order of hit rates:** $twolf.trace > gcc.trace > swim.trace > gzip.trace > mcf.trace)$

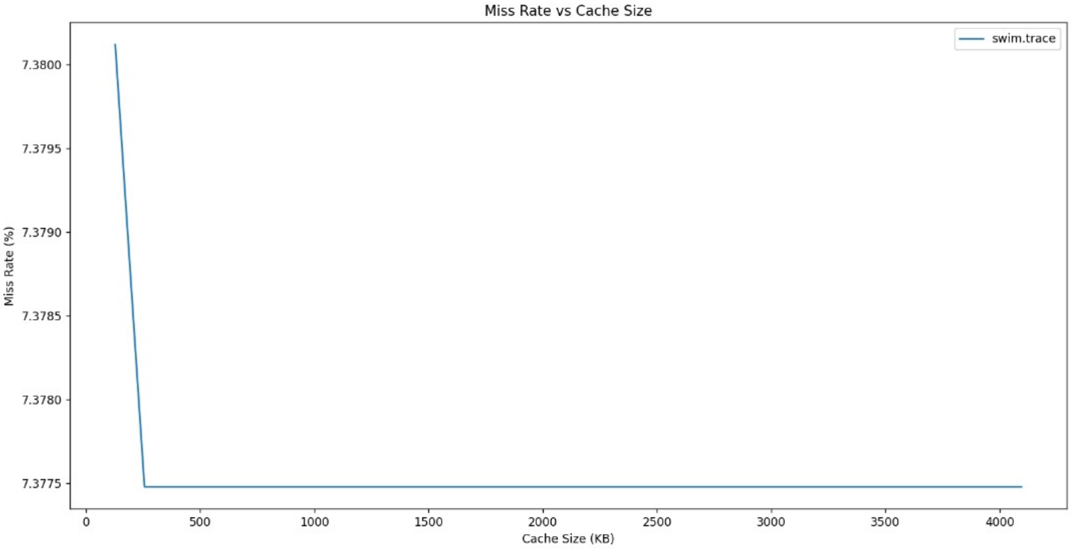
2.2 b) 4-way set-associative cache with varying cache size

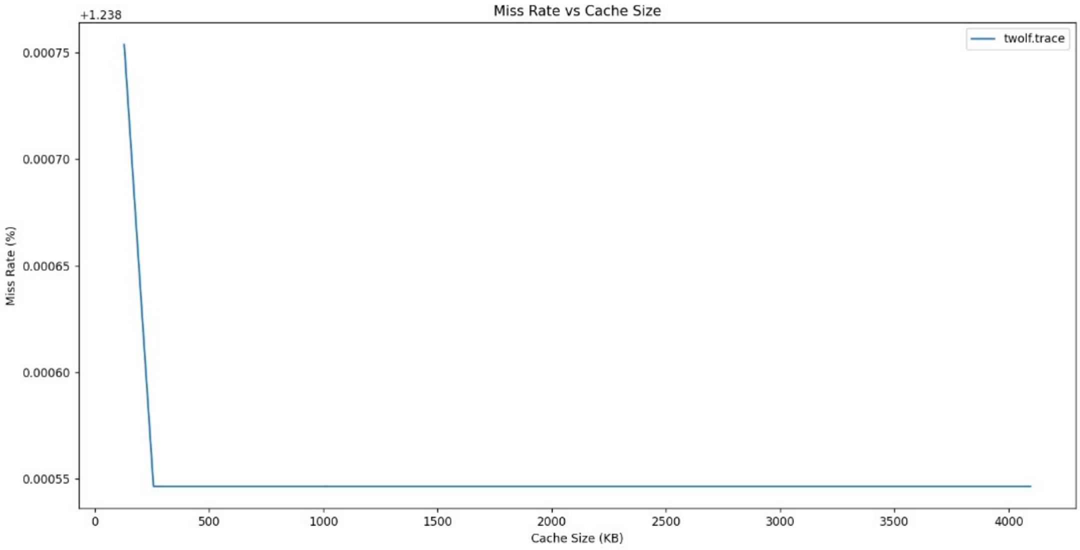
- **In this experiment, the cache size was varied from 128 kB to 4096 kB to observe the effect on cache performance, specifically the miss rate.**
- **The goal was to analyze how increasing cache size impacts the cache's ability to store more data and reduce the number of misses.**
- **The simulation was run across multiple trace files, and the miss rate for each trace was recorded and plotted.**

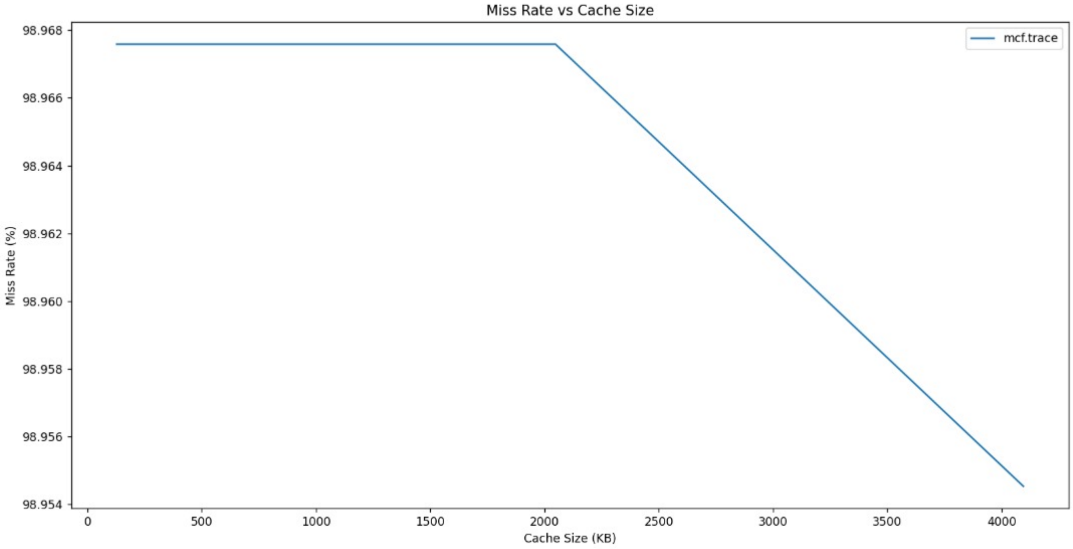

Miss Rate vs Cache Size
Miss Rate (%)
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
3500
4000
Cache Size (KB)
Trace 1
Trace 2
Trace 3
Trace 4
Trace 5


Miss Rate vs Cache Size
Miss Rate (%)
6.200
6.195
6.190
6.185
6.180
6.175
6.170
6.165
0
500
1000
1500
2000
2500
3000
3500
4000
Cache Size (KB)
gcc.trace


Miss Rate vs Cache Size
gzip.trace
Miss Rate (%)
35.0
34.5
34.0
33.5
33.0
32.5
32.0
31.5
0
500
1000
1500
2000
2500
3000
3500
4000
Cache Size (KB)

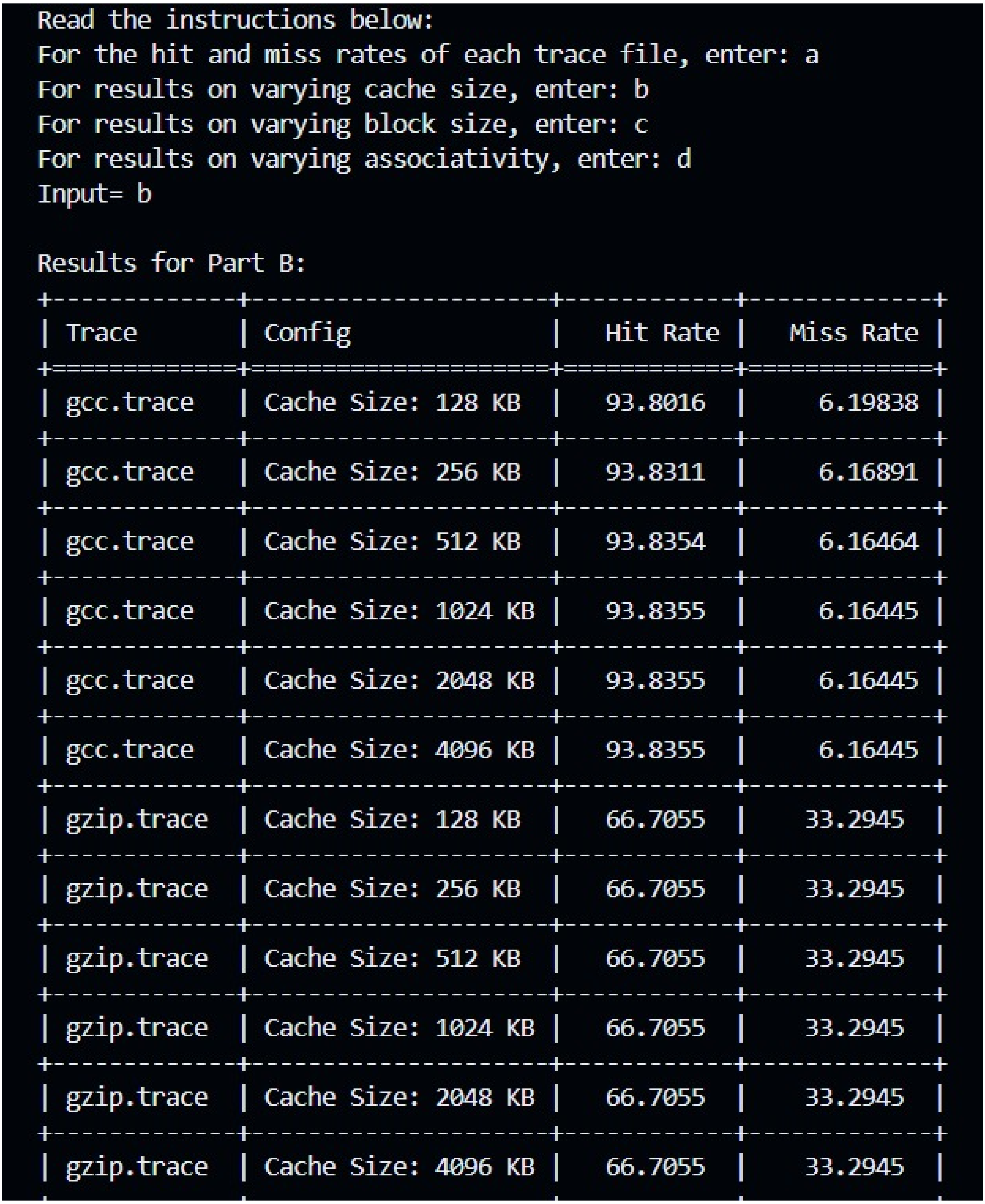

Miss Rate vs Cache Size
swim.trace
Miss Rate (%)
7.3800
7.3795
7.3790
7.3785
7.3780
7.3775
0
500
1000
1500
2000
2500
3000
3500
4000
Cache Size (KB)



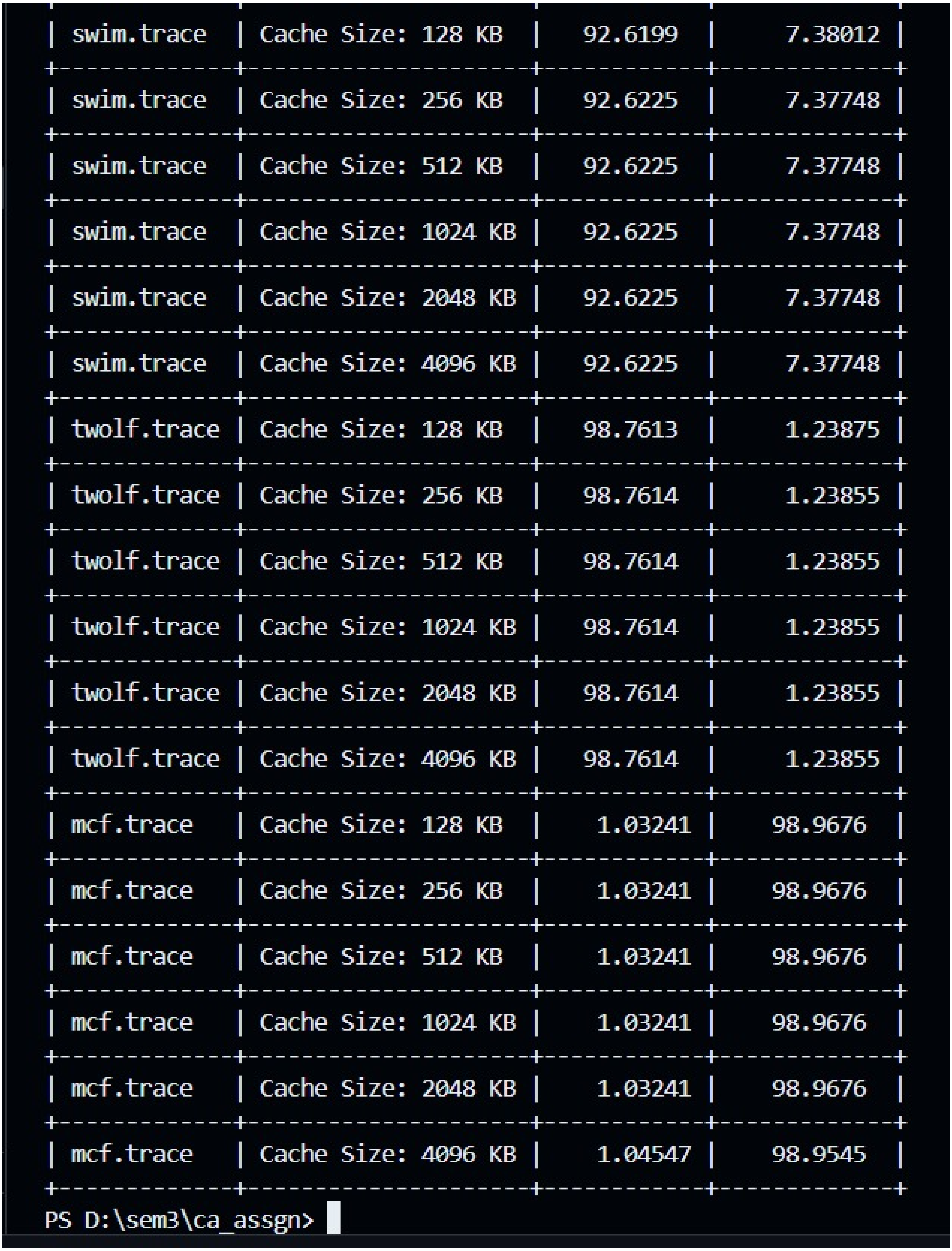


Observations:

- **All the traces do not behave the same way. We can see that even after varying the cache size, changes in miss rates are very minute.**
- **This indicates that the cache is not exploiting temporal and spatial locality to a large extent.**
- **Hence, we have put individual graphs highlighting these minute differences in the miss rates.**



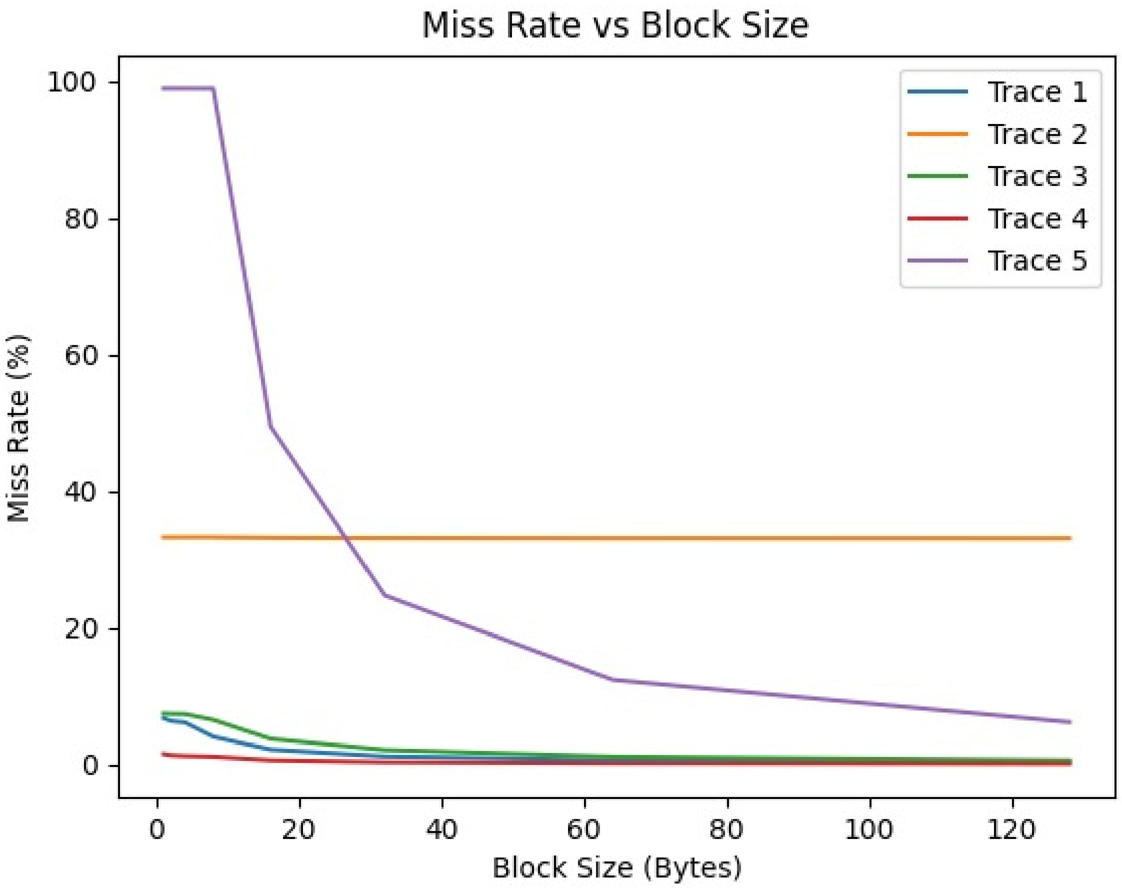
```
Read the instructions below:
For the hit and miss rates of each trace file, enter: a
For results on varying cache size, enter: b
For results on varying block size, enter: c
For results on varying associativity, enter: d
Input= b

Results for Part B:
+-------------+---------------------+------------+-------------+
| Trace       | Config              |   Hit Rate |   Miss Rate |
+=============+=====================+============+=============+
| gcc.trace   | Cache Size: 128 KB  |    93.8016 |     6.19838 |
+-------------+---------------------+------------+-------------+
| gcc.trace   | Cache Size: 256 KB  |    93.8311 |     6.16891 |
+-------------+---------------------+------------+-------------+
| gcc.trace   | Cache Size: 512 KB  |    93.8354 |     6.16464 |
+-------------+---------------------+------------+-------------+
| gcc.trace   | Cache Size: 1024 KB |    93.8355 |     6.16445 |
+-------------+---------------------+------------+-------------+
| gcc.trace   | Cache Size: 2048 KB |    93.8355 |     6.16445 |
+-------------+---------------------+------------+-------------+
| gcc.trace   | Cache Size: 4096 KB |    93.8355 |     6.16445 |
+-------------+---------------------+------------+-------------+
| gzip.trace  | Cache Size: 128 KB  |    66.7055 |    33.2945  |
+-------------+---------------------+------------+-------------+
| gzip.trace  | Cache Size: 256 KB  |    66.7055 |    33.2945  |
+-------------+---------------------+------------+-------------+
| gzip.trace  | Cache Size: 512 KB  |    66.7055 |    33.2945  |
+-------------+---------------------+------------+-------------+
| gzip.trace  | Cache Size: 1024 KB |    66.7055 |    33.2945  |
+-------------+---------------------+------------+-------------+
| gzip.trace  | Cache Size: 2048 KB |    66.7055 |    33.2945  |
+-------------+---------------------+------------+-------------+
| gzip.trace  | Cache Size: 4096 KB |    66.7055 |    33.2945  |
```

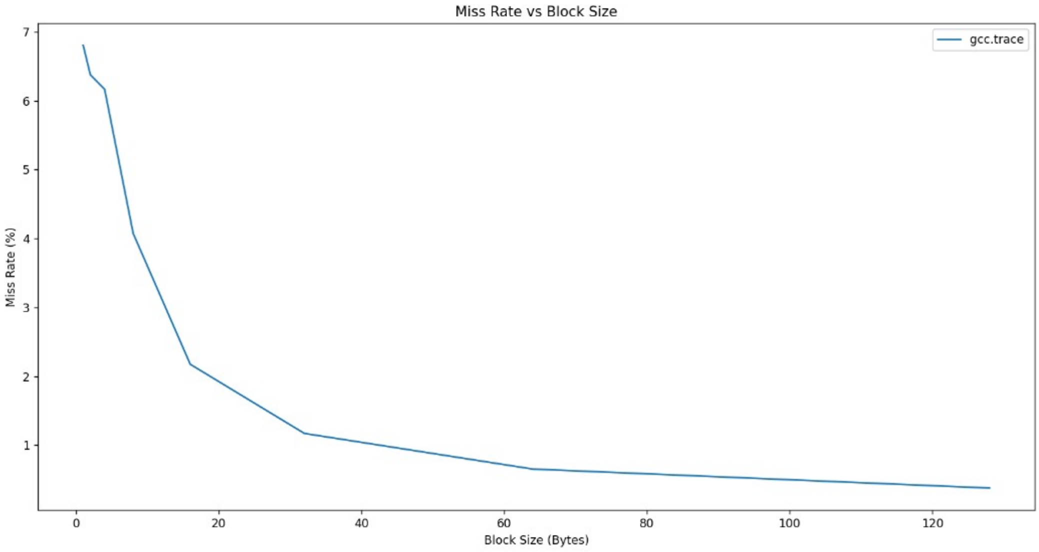


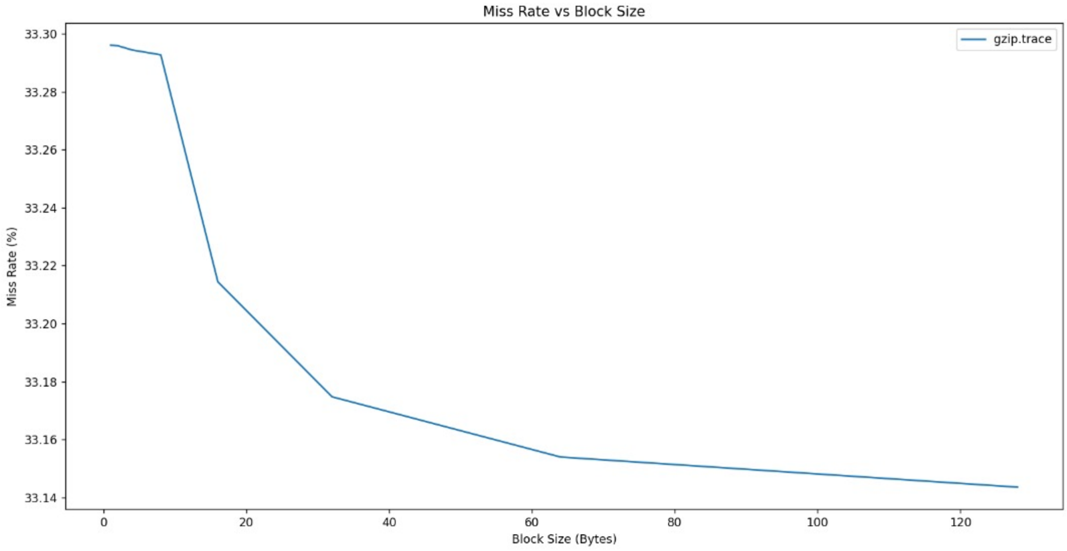
```
| swim.trace  | Cache Size: 128 KB  |   92.6199  |     7.38012 |
+-------------+---------------------+------------+-------------+
| swim.trace  | Cache Size: 256 KB  |   92.6225  |     7.37748 |
+-------------+---------------------+------------+-------------+
| swim.trace  | Cache Size: 512 KB  |   92.6225  |     7.37748 |
+-------------+---------------------+------------+-------------+
| swim.trace  | Cache Size: 1024 KB |   92.6225  |     7.37748 |
+-------------+---------------------+------------+-------------+
| swim.trace  | Cache Size: 2048 KB |   92.6225  |     7.37748 |
+-------------+---------------------+------------+-------------+
| swim.trace  | Cache Size: 4096 KB |   92.6225  |     7.37748 |
+-------------+---------------------+------------+-------------+
| twolf.trace | Cache Size: 128 KB  |   98.7613  |     1.23875 |
+-------------+---------------------+------------+-------------+
| twolf.trace | Cache Size: 256 KB  |   98.7614  |     1.23855 |
+-------------+---------------------+------------+-------------+
| twolf.trace | Cache Size: 512 KB  |   98.7614  |     1.23855 |
+-------------+---------------------+------------+-------------+
| twolf.trace | Cache Size: 1024 KB |   98.7614  |     1.23855 |
+-------------+---------------------+------------+-------------+
| twolf.trace | Cache Size: 2048 KB |   98.7614  |     1.23855 |
+-------------+---------------------+------------+-------------+
| twolf.trace | Cache Size: 4096 KB |   98.7614  |     1.23855 |
+-------------+---------------------+------------+-------------+
| mcf.trace   | Cache Size: 128 KB  |    1.03241 |    98.9676  |
+-------------+---------------------+------------+-------------+
| mcf.trace   | Cache Size: 256 KB  |    1.03241 |    98.9676  |
+-------------+---------------------+------------+-------------+
| mcf.trace   | Cache Size: 512 KB  |    1.03241 |    98.9676  |
+-------------+---------------------+------------+-------------+
| mcf.trace   | Cache Size: 1024 KB |    1.03241 |    98.9676  |
+-------------+---------------------+------------+-------------+
| mcf.trace   | Cache Size: 2048 KB |    1.03241 |    98.9676  |
+-------------+---------------------+------------+-------------+
| mcf.trace   | Cache Size: 4096 KB |    1.04547 |    98.9545  |
+-------------+---------------------+------------+-------------+
PS D:\sem3\ca_assgn>
```

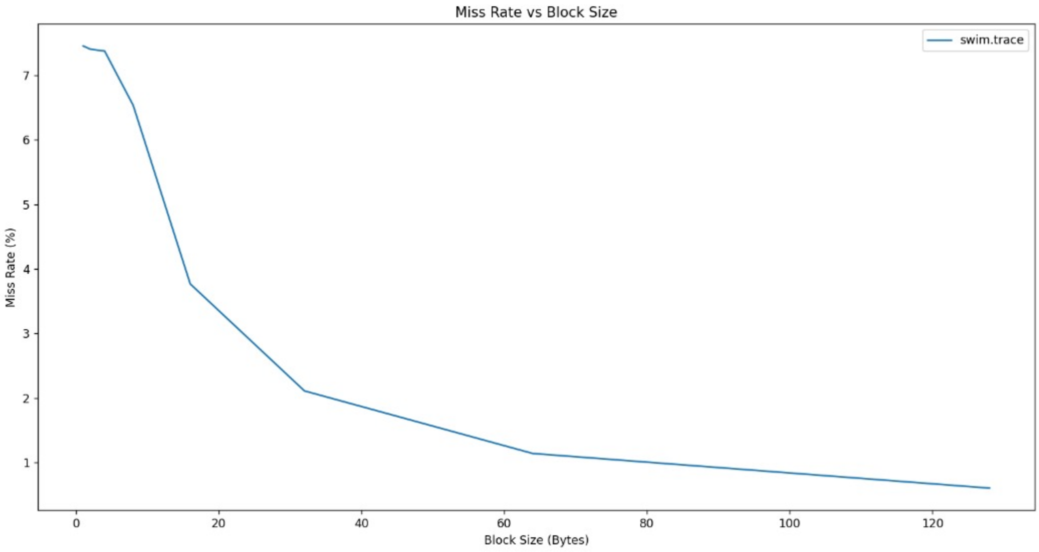
2.3 c) 4-way set-associative cache with varying blockSize

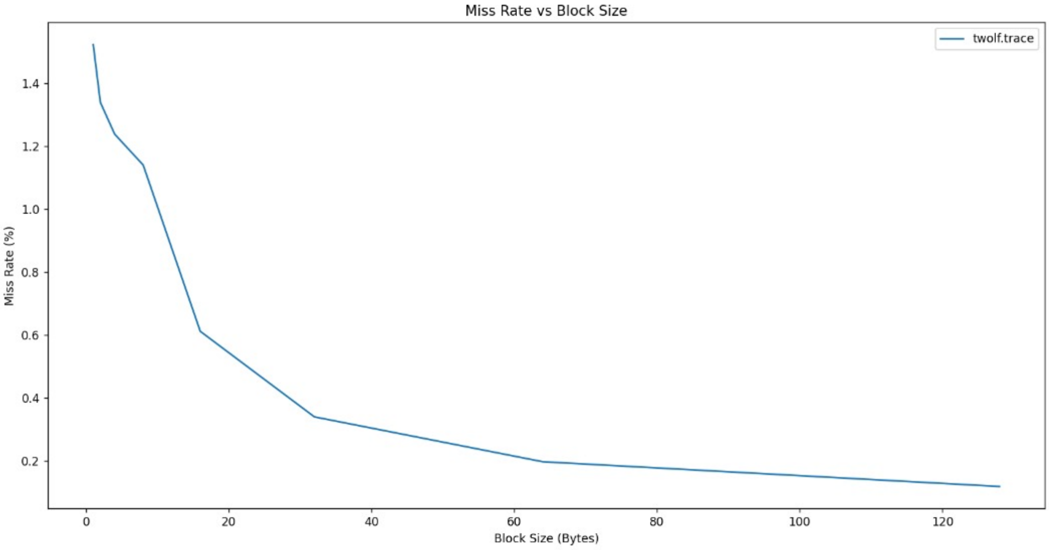
- In this experiment, the **cache size was fixed at 1024 kB**, and the block size was varied from **1 byte to 128 bytes**.
- The purpose was to study how changing the block size affects the miss rate, considering that larger block sizes reduce the number of cache lines available.
- The simulation was repeated for all trace files, and the miss rates were plotted against block size for each trace.

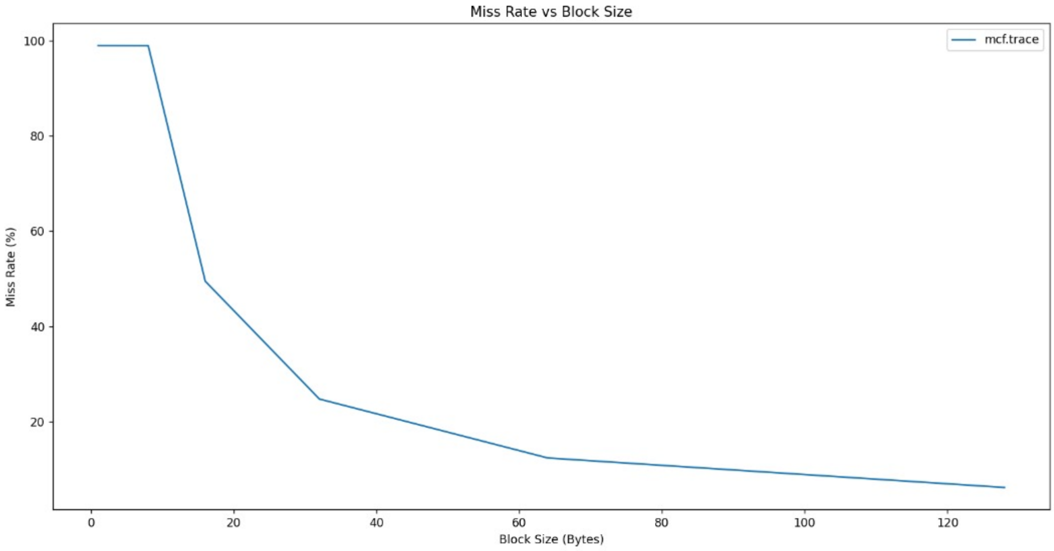


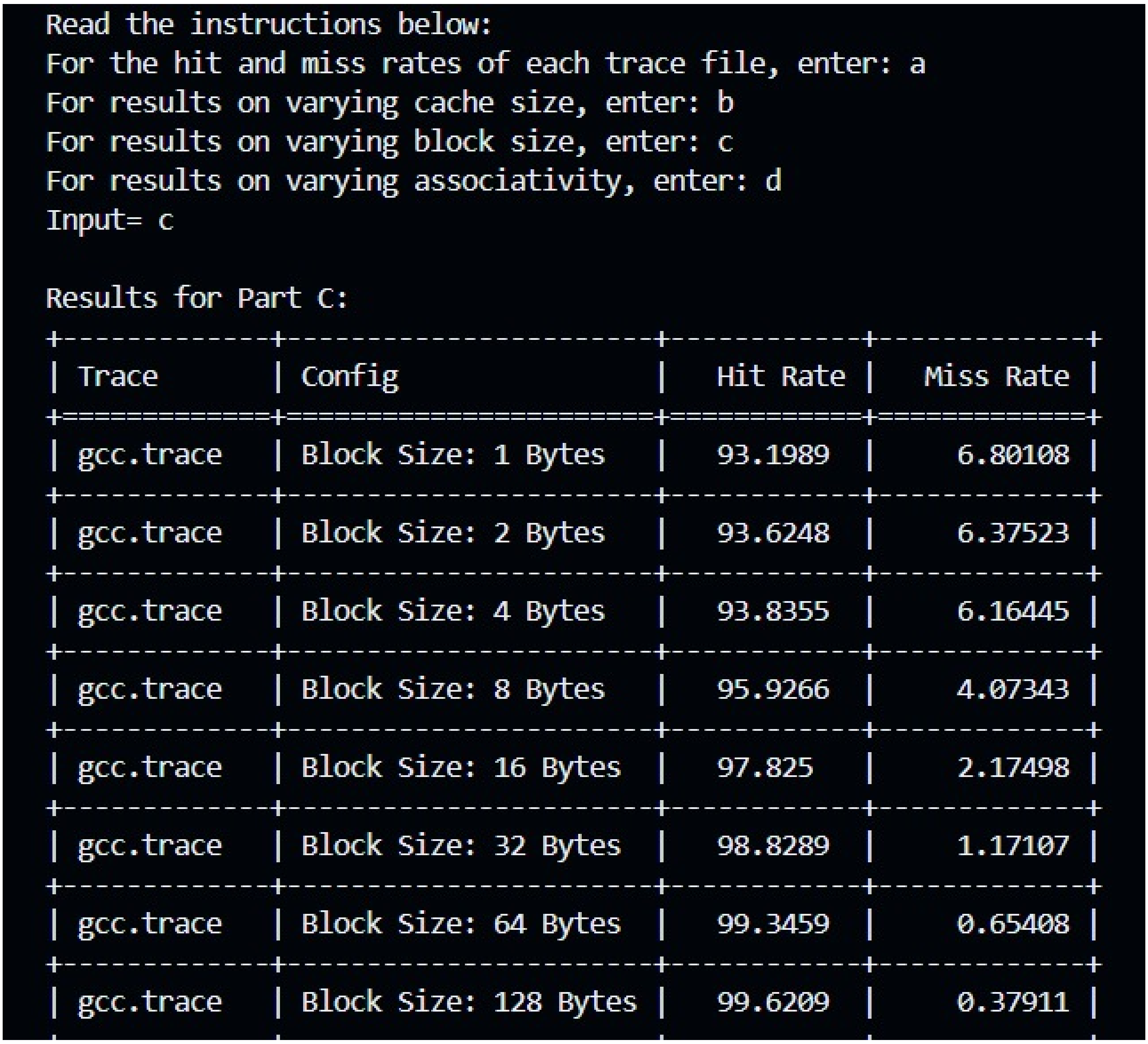

Miss Rate vs Block Size
gcc.trace
Miss Rate (%)
7
6
5
4
3
2
1
0
20
40
60
80
100
120
Block Size (Bytes)


Miss Rate vs Block Size
gzip.trace
Miss Rate (%)
33.30
33.28
33.26
33.24
33.22
33.20
33.18
33.16
33.14
0
20
40
60
80
100
120
Block Size (Bytes)


Miss Rate vs Block Size
swim.trace
Miss Rate (%)
1
2
3
4
5
6
7
0
20
40
60
80
100
120
Block Size (Bytes)

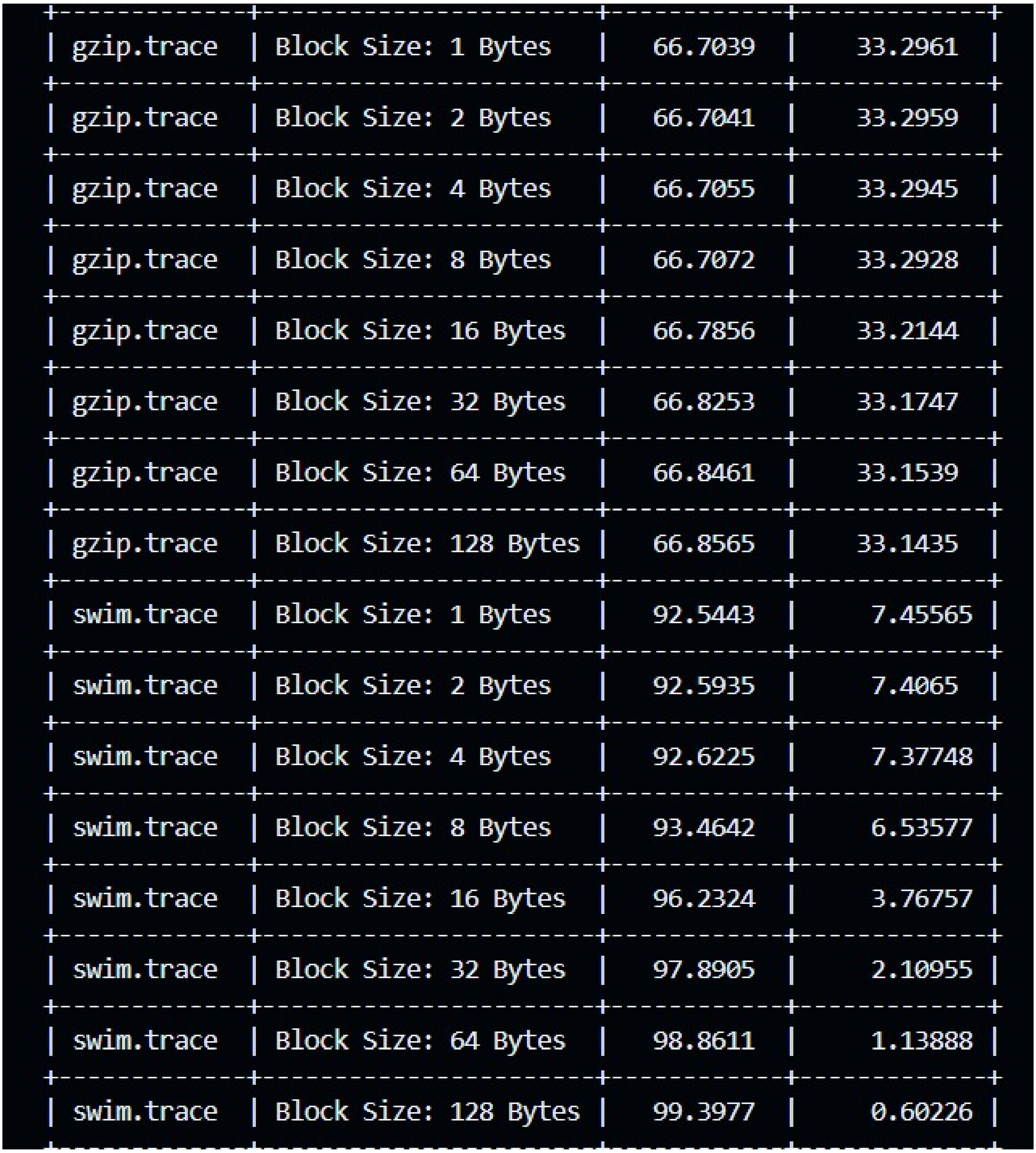

Miss Rate vs Block Size
twolf.trace
Miss Rate (%)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
20
40
60
80
100
120
Block Size (Bytes)


Miss Rate vs Block Size
mcf.trace
Miss Rate (%)
100
80
60
40
20
0
20
40
60
80
100
120
Block Size (Bytes)



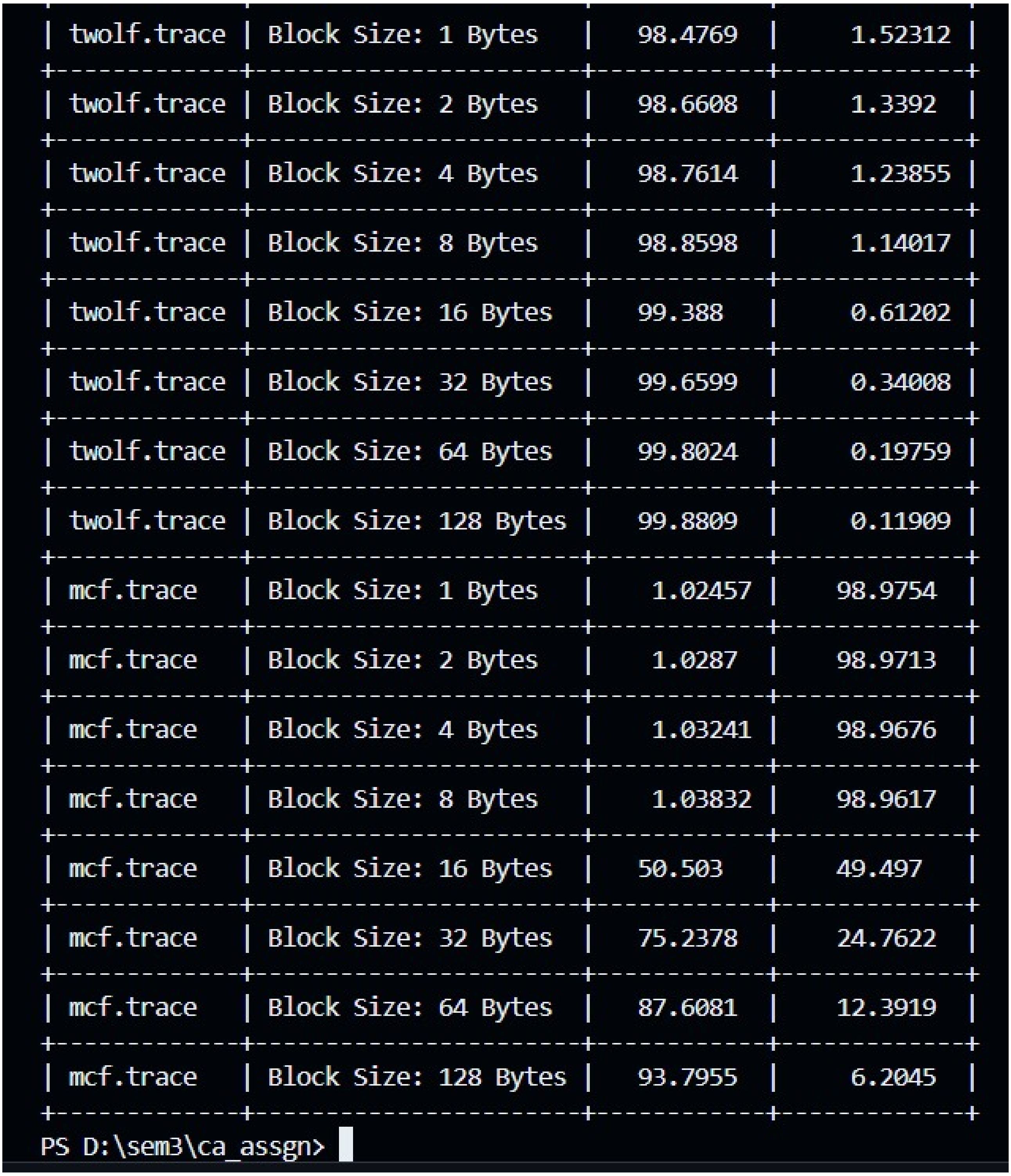
```
Read the instructions below:
For the hit and miss rates of each trace file, enter: a
For results on varying cache size, enter: b
For results on varying block size, enter: c
For results on varying associativity, enter: d
Input= c

Results for Part C:
+-------------+-----------------------+------------+-------------+
| Trace       | Config                |   Hit Rate |   Miss Rate |
+=============+=======================+============+=============+
| gcc.trace   | Block Size: 1 Bytes   |    93.1989 |     6.80108 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 2 Bytes   |    93.6248 |     6.37523 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 4 Bytes   |    93.8355 |     6.16445 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 8 Bytes   |    95.9266 |     4.07343 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 16 Bytes  |    97.825  |     2.17498 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 32 Bytes  |    98.8289 |     1.17107 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 64 Bytes  |    99.3459 |     0.65408 |
+-------------+-----------------------+------------+-------------+
| gcc.trace   | Block Size: 128 Bytes |    99.6209 |     0.37911 |
```

Enter Caption



```
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 1 Bytes    |   66.7039  |    33.2961  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 2 Bytes    |   66.7041  |    33.2959  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 4 Bytes    |   66.7055  |    33.2945  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 8 Bytes    |   66.7072  |    33.2928  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 16 Bytes   |   66.7856  |    33.2144  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 32 Bytes   |   66.8253  |    33.1747  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 64 Bytes   |   66.8461  |    33.1539  |
+-------------+------------------------+------------+-------------+
| gzip.trace  | Block Size: 128 Bytes  |   66.8565  |    33.1435  |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 1 Bytes    |   92.5443  |     7.45565 |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 2 Bytes    |   92.5935  |     7.4065  |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 4 Bytes    |   92.6225  |     7.37748 |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 8 Bytes    |   93.4642  |     6.53577 |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 16 Bytes   |   96.2324  |     3.76757 |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 32 Bytes   |   97.8905  |     2.10955 |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 64 Bytes   |   98.8611  |     1.13888 |
+-------------+------------------------+------------+-------------+
| swim.trace  | Block Size: 128 Bytes  |   99.3977  |     0.60226 |
```

Enter Caption



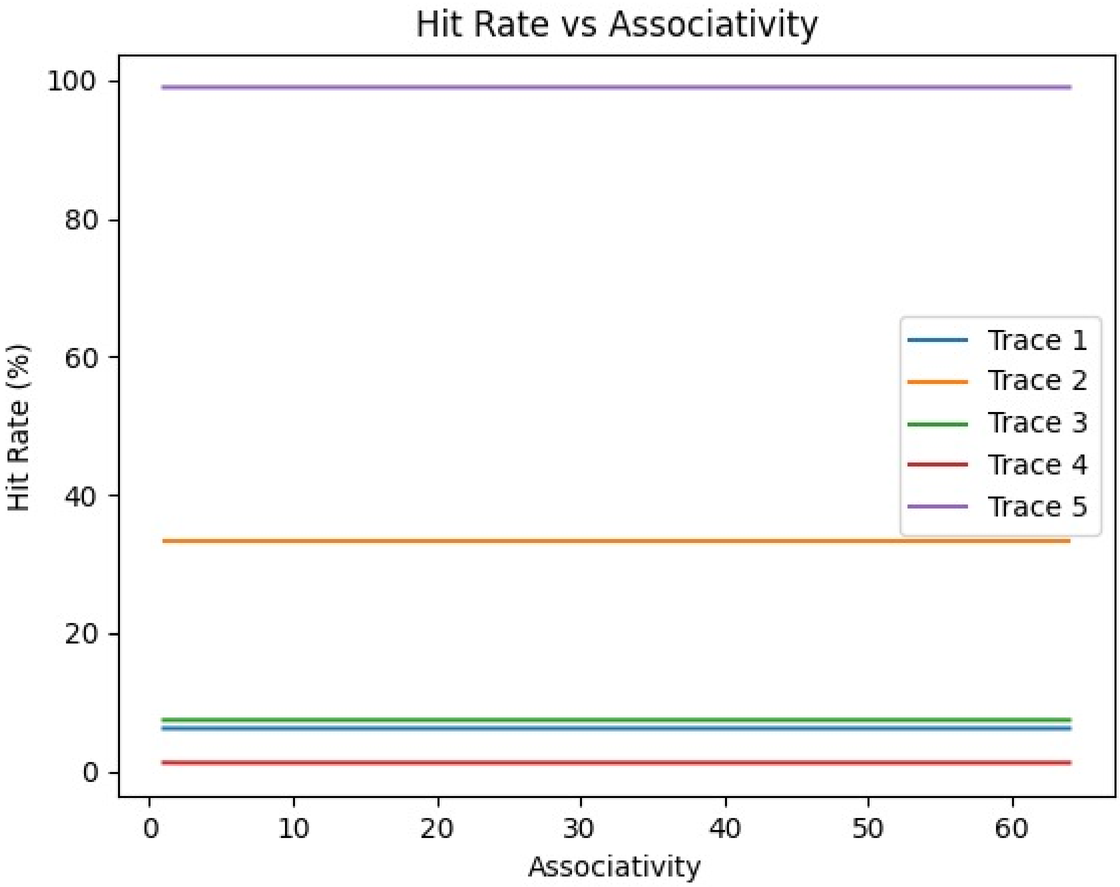
```
| twolf.trace | Block Size: 1 Bytes   |   98.4769  |     1.52312 |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 2 Bytes   |   98.6608  |     1.3392  |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 4 Bytes   |   98.7614  |     1.23855 |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 8 Bytes   |   98.8598  |     1.14017 |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 16 Bytes  |   99.388   |     0.61202 |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 32 Bytes  |   99.6599  |     0.34008 |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 64 Bytes  |   99.8024  |     0.19759 |
+-------------+-----------------------+------------+-------------+
| twolf.trace | Block Size: 128 Bytes |   99.8809  |     0.11909 |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 1 Bytes   |    1.02457 |   98.9754   |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 2 Bytes   |    1.0287  |   98.9713   |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 4 Bytes   |    1.03241 |   98.9676   |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 8 Bytes   |    1.03832 |   98.9617   |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 16 Bytes  |   50.503   |   49.497    |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 32 Bytes  |   75.2378  |   24.7622   |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 64 Bytes  |   87.6081  |   12.3919   |
+-------------+-----------------------+------------+-------------+
| mcf.trace   | Block Size: 128 Bytes |   93.7955  |    6.2045   |
+-------------+-----------------------+------------+-------------+
PS D:\sem3\ca_assgn>
```

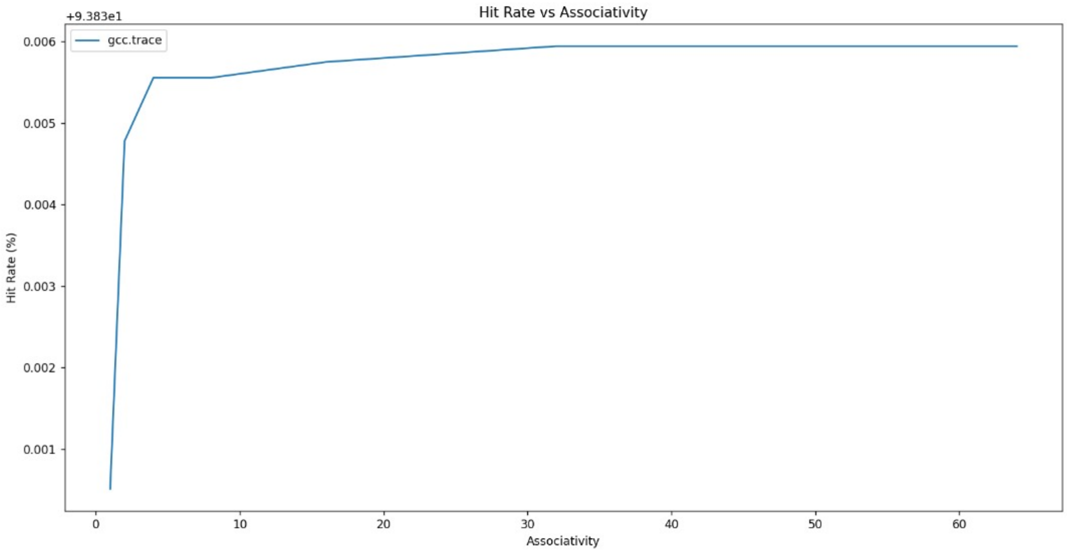
Observations:

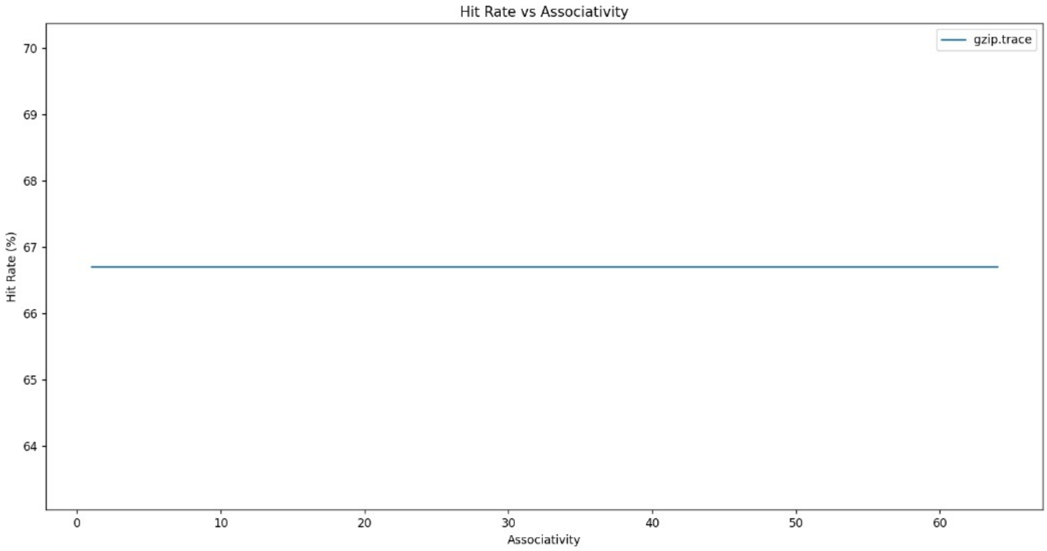
- **The traces behave the same way and the miss rates decrease as we increase block size.**
- **Thus by increasing the block size we are taking advantage of spatial locality (which means consecutive bytes need not be fetched again)**
- **From the table we infer that hit rates increase for a particular trace file very slightly**

2.4 d) set-associative Cache with varying number of ways :

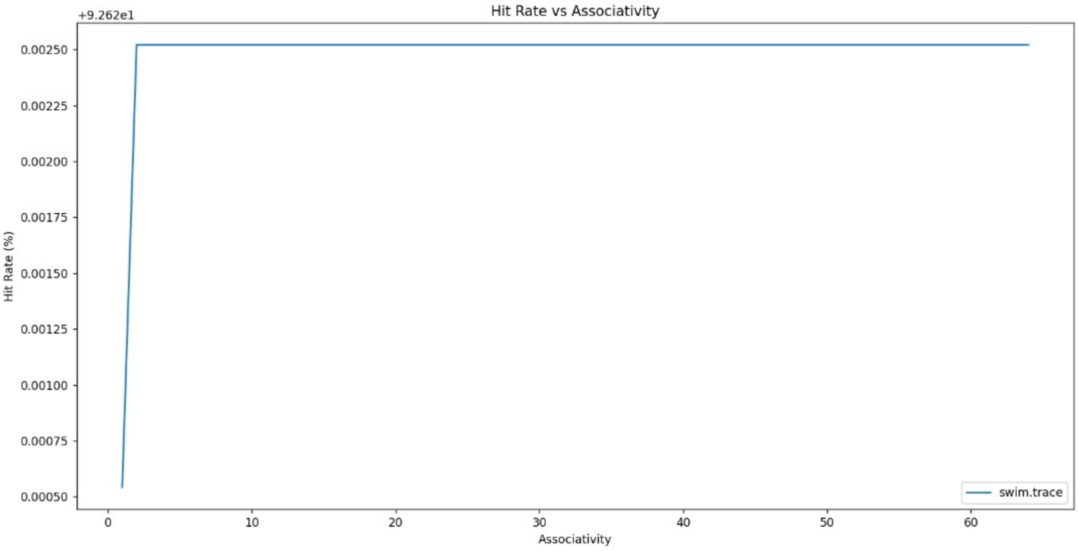
- **To analyze the effect of cache associativity on the performance of the cache system, we fixed the cache size at 1024kB and systematically varied the associativity levels from 1-way (direct-mapped) to 64-way associative.**

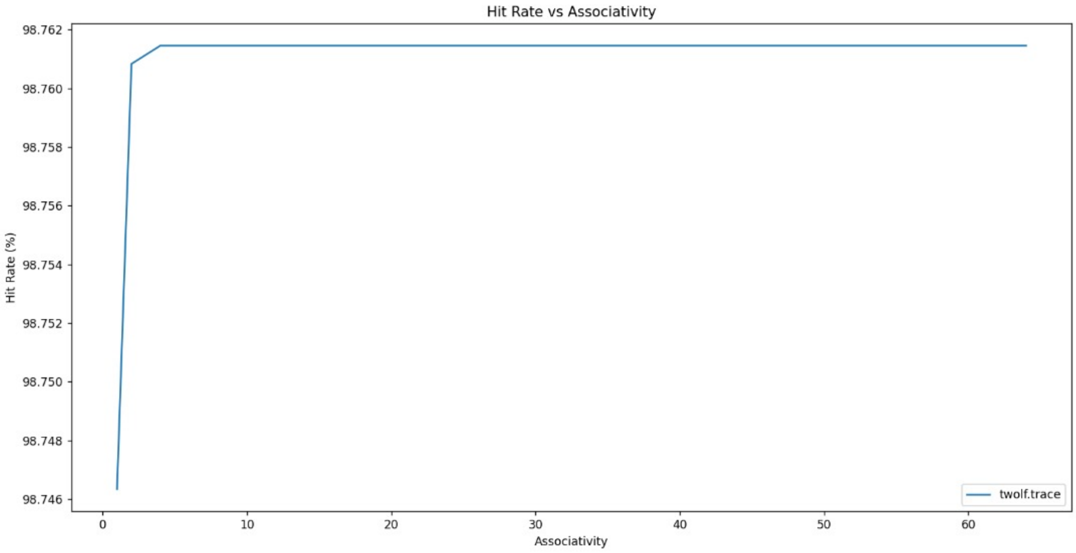


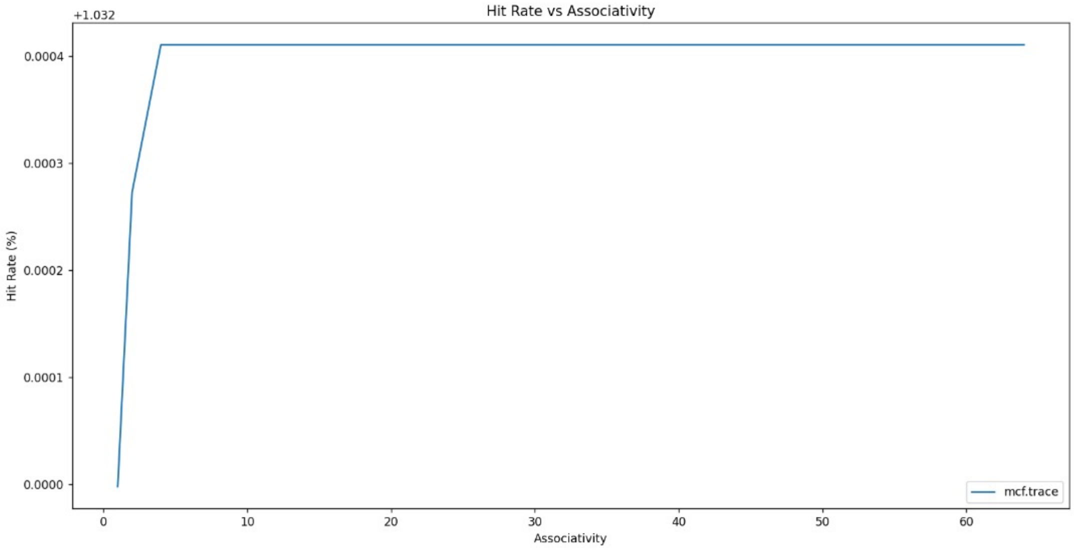


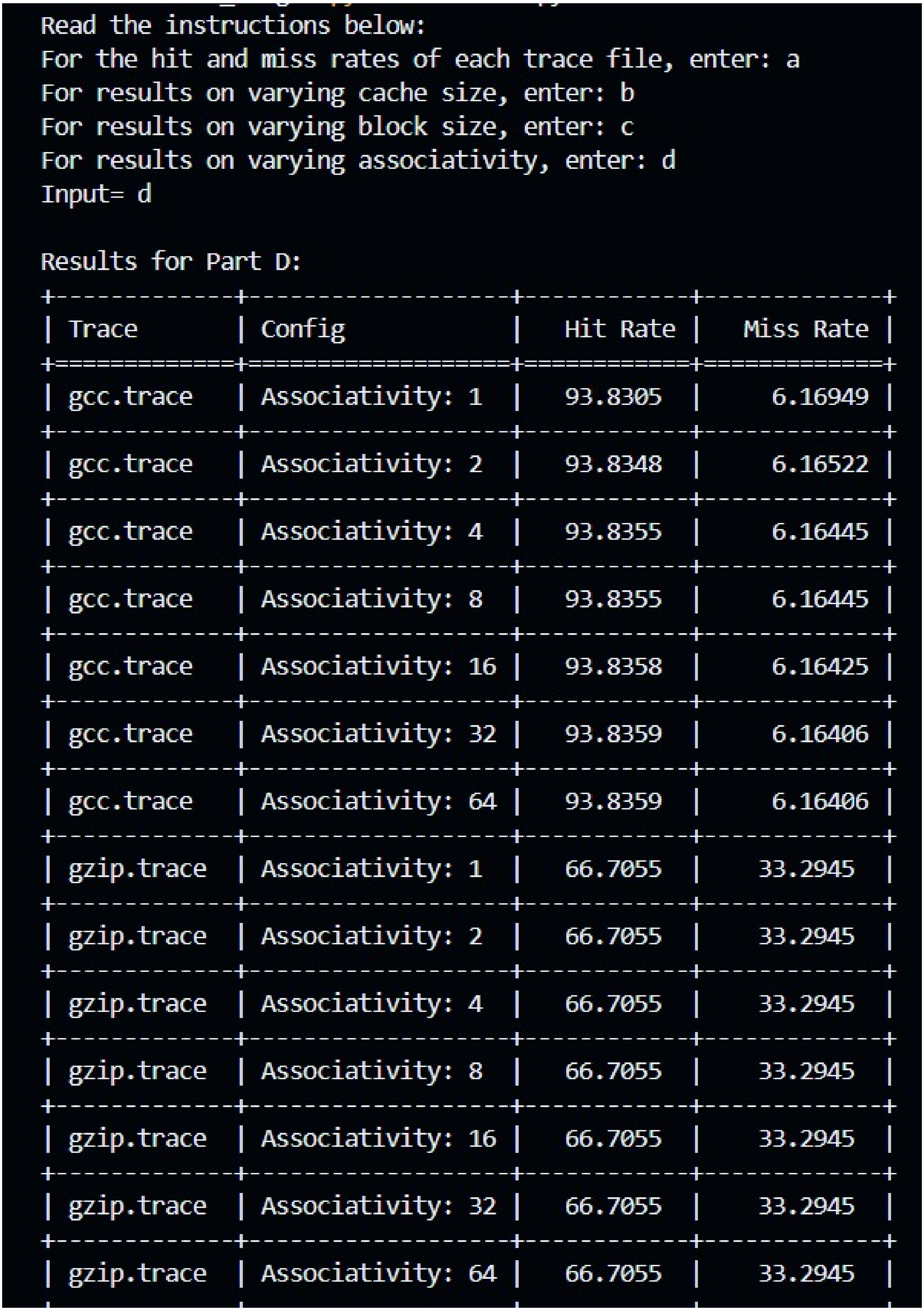

Hit Rate vs Associativity
gzip.trace
Hit Rate (%)
70
69
68
67
66
65
64
0
10
20
30
40
50
60
Associativity

–

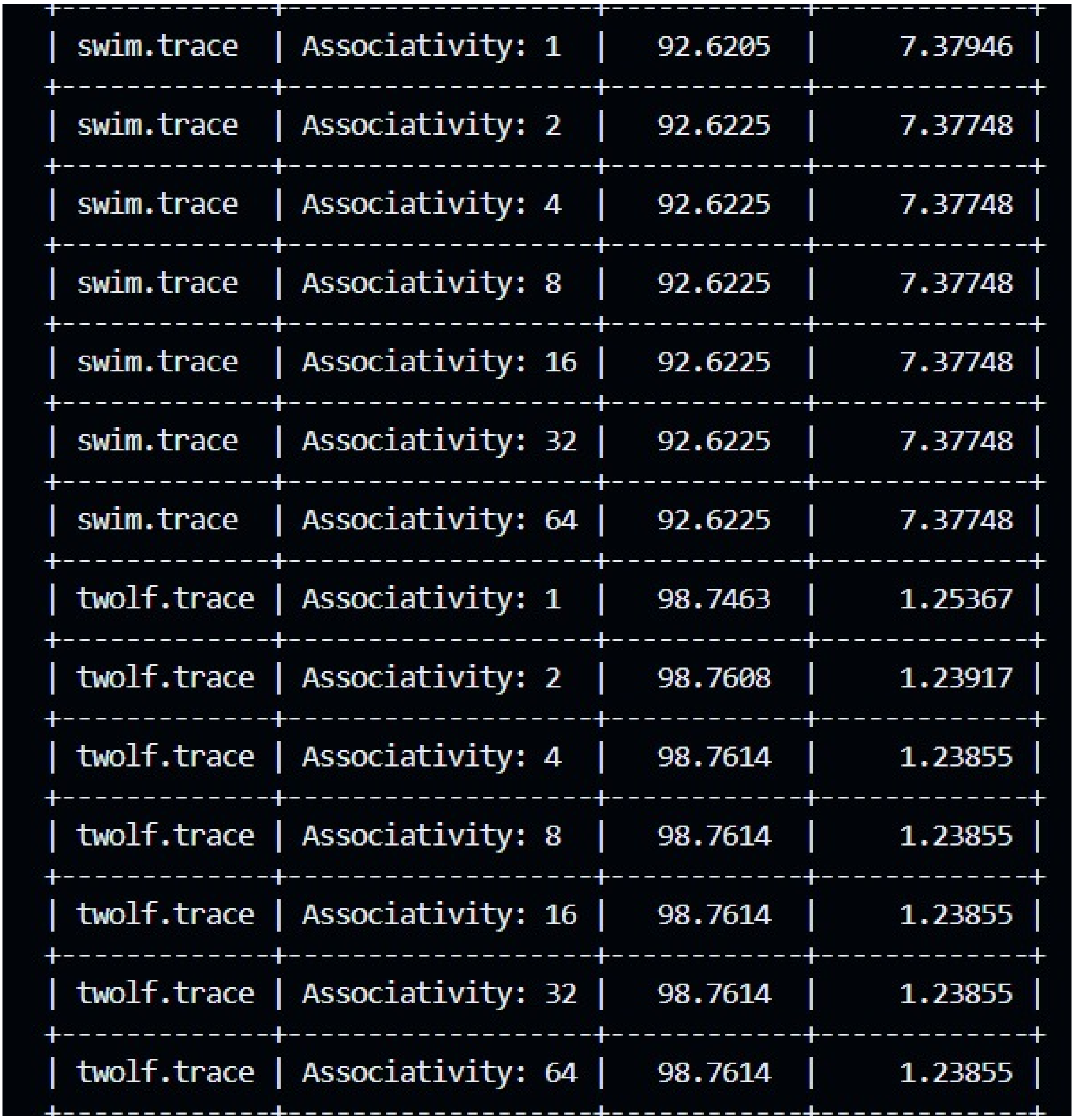

Hit Rate vs Associativity
+9.262e1
0.00250
0.00225
0.00200
0.00175
0.00150
0.00125
0.00100
0.00075
0.00050
Hit Rate (%)
swim.trace
0
10
20
30
40
50
60
Associativity


Hit Rate vs Associativity
98.762
98.760
98.758
98.756
98.754
98.752
98.750
98.748
98.746
Hit Rate (%)
0
10
20
30
40
50
60
Associativity
twolf.trace

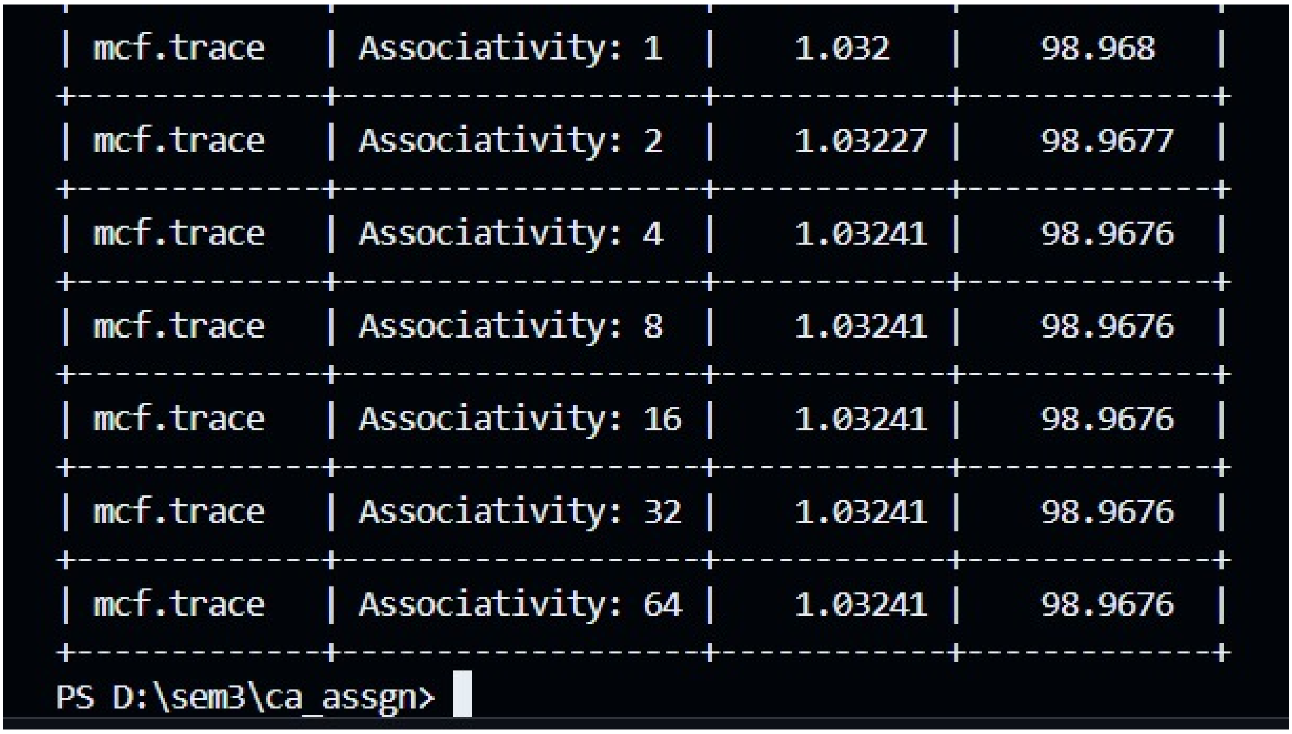

+1.032
Hit Rate vs Associativity
0.0004
0.0003
0.0002
0.0001
0.0000
Hit Rate (%)
0
10
20
30
40
50
60
Associativity
mcf.trace



```
Read the instructions below:
For the hit and miss rates of each trace file, enter: a
For results on varying cache size, enter: b
For results on varying block size, enter: c
For results on varying associativity, enter: d
Input= d

Results for Part D:
+-------------+-------------------+------------+-------------+
| Trace       | Config            |   Hit Rate |   Miss Rate |
+=============+===================+============+=============+
| gcc.trace   | Associativity: 1  |   93.8305  |     6.16949 |
+-------------+-------------------+------------+-------------+
| gcc.trace   | Associativity: 2  |   93.8348  |     6.16522 |
+-------------+-------------------+------------+-------------+
| gcc.trace   | Associativity: 4  |   93.8355  |     6.16445 |
+-------------+-------------------+------------+-------------+
| gcc.trace   | Associativity: 8  |   93.8355  |     6.16445 |
+-------------+-------------------+------------+-------------+
| gcc.trace   | Associativity: 16 |   93.8358  |     6.16425 |
+-------------+-------------------+------------+-------------+
| gcc.trace   | Associativity: 32 |   93.8359  |     6.16406 |
+-------------+-------------------+------------+-------------+
| gcc.trace   | Associativity: 64 |   93.8359  |     6.16406 |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 1  |   66.7055  |    33.2945  |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 2  |   66.7055  |    33.2945  |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 4  |   66.7055  |    33.2945  |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 8  |   66.7055  |    33.2945  |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 16 |   66.7055  |    33.2945  |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 32 |   66.7055  |    33.2945  |
+-------------+-------------------+------------+-------------+
| gzip.trace  | Associativity: 64 |   66.7055  |    33.2945  |
```



```
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 1   |  92.6205   |     7.37946 |
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 2   |  92.6225   |     7.37748 |
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 4   |  92.6225   |     7.37748 |
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 8   |  92.6225   |     7.37748 |
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 16  |  92.6225   |     7.37748 |
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 32  |  92.6225   |     7.37748 |
+-------------+--------------------+------------+-------------+
| swim.trace  | Associativity: 64  |  92.6225   |     7.37748 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 1   |  98.7463   |     1.25367 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 2   |  98.7608   |     1.23917 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 4   |  98.7614   |     1.23855 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 8   |  98.7614   |     1.23855 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 16  |  98.7614   |     1.23855 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 32  |  98.7614   |     1.23855 |
+-------------+--------------------+------------+-------------+
| twolf.trace | Associativity: 64  |  98.7614   |     1.23855 |
+-------------+--------------------+------------+-------------+
```



```
| mcf.trace    | Associativity: 1  |    1.032   |    98.968   |
+-------------+------------------+-----------+------------+
| mcf.trace    | Associativity: 2  |    1.03227 |    98.9677  |
+-------------+------------------+-----------+------------+
| mcf.trace    | Associativity: 4  |    1.03241 |    98.9676  |
+-------------+------------------+-----------+------------+
| mcf.trace    | Associativity: 8  |    1.03241 |    98.9676  |
+-------------+------------------+-----------+------------+
| mcf.trace    | Associativity: 16 |    1.03241 |    98.9676  |
+-------------+------------------+-----------+------------+
| mcf.trace    | Associativity: 32 |    1.03241 |    98.9676  |
+-------------+------------------+-----------+------------+
| mcf.trace    | Associativity: 64 |    1.03241 |    98.9676  |
+-------------+------------------+-----------+------------+
PS D:\sem3\ca_assgn>
```

Observations:

- **gzip.trace input file graph obtained is different from other four graphs.**
- **Generally hit rates increases while increasing associativity but it depends on different input files.**
- **Thus the file gzip.trace is behaving differently due to its memory access patterns that does not cause many conflicts between indexes.**