COMPUTER ARCHITECTURE PROJECT

CACHE IMPLEMENTATION

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Abstract:

In this project, we implement two types of caches, Direct Mapped Cache and Set Associative Cache with the FIFO cache replacement algorithm.

We used the python programming language to simulate cache mapping and take input from the given trace files.

INSTRUCTIONS TO RUN

1. Unzip the file provided.
2. Then, in the command line, enter

   > chmod +x IMT2019525.sh

3. Then, enter

   > ./IMT2019525

To run the DM cache simulations with a standalone trace file located at absolute location *PATH*, please enter

> python3 direct_mapped_cache.py -f “PATH”

To run the DM cache simulations with a standalone trace file located at absolute location *PATH*, please enter

> python3 set_associative_cache.py -f “PATH”

The implementation can be seen here (run with Python 3.6.9):

https://asciinema.org/a/JJrDbT7LLnVUUrm10xcpNhai5

OBSERVATIONS

The observations file is appended to this report. For the native python implementation, please see *observations.ipynb.*

PROJECT CONTENTS

This project submission contains the following files:

- direct_mapped_cache.py - This contains the implementation of the DM cache
- set_associative_cache.py - This contains the implementation of the SA cache

- IMT2019525.sh - This is the shell script used to execute the files in order, taking the trace files as input
- traces – This is the folder containing the trace files:
    - Gcc.trace
    - Gzip.trace
    - Mcf.trace
    - Swim.trace
    - Twolf.trace

CACHE HIT/MISS RATES

These are the values for the Direct Mapped Cache:

FILE NAME	HIT RATE	MISS RATE	HIT/MISS RATIO
Gcc.trace	0.958346503569053	0.04165349643094696	23.007588454376165
Gzip.trace	0.6670720349905622	0.3329279650094378	2.00365275705107
Mcf.trace	0.01037910977269914	0.9896208902273008	0.010487965518103829
Swim.trace	0.9343190640944876	0.06568093590551238	14.225118007431957

Twolf.trace	0.988442993720279	0.0115570062797210 1	85.52759856630824

These are the values for the Set Associative Cache:

FILE NAME	HIT RATE	MISS RATE	HIT/MISS RATIO
Gcc.trace	0.9382799122716863	0.06172008772831372	15.202180470026391
Gzip.trace	0.6670554044952229	0.33294459550477706	2.003502725382584
Mcf.trace	0.010325481622045295	0.9896745183779547	0.010433209535361618
Swim.trace	0.9262252096849202	0.07377479031507983	12.554765736766809
Twolf.trace	0.9876145344887578	0.0123854655112422	79.73979933110368

CALCULATIONS

For the DM cache,

- Number of offset bits = 2
- Number of index bits = 16
- Number of tag bits = 14

For the SA cache,

- Number of offset bits = 2
- Number of index bits = 14
- Number of tag bits = 16

MISCELLANEOUS NOTES

- We use a new Cache (I.e a new Object for every run of the program)
- We have used the FIFO(First-In-First-Out) algorithm, which is explained in *Observations.ipynb* (whose pdf file is appended to this report)
- This experiment serves as the *Null Hypothesis* for the statement “SA cache is always better than DM cache”. We see that the replacement algorithm, among other factors, plays a major part in hit rate.

The observations file follows here. It was made using Jupyter Notebook and matplotlib, whose native python implementation can be found in the submission.

Observations

November 22, 2020

0.1 Observations and Measurements

0.1.1 Done By: IMT2019525 VIJAY JAISANKAR

Importing necessary libraries

[1]:
```
import matplotlib.pyplot as plt
```

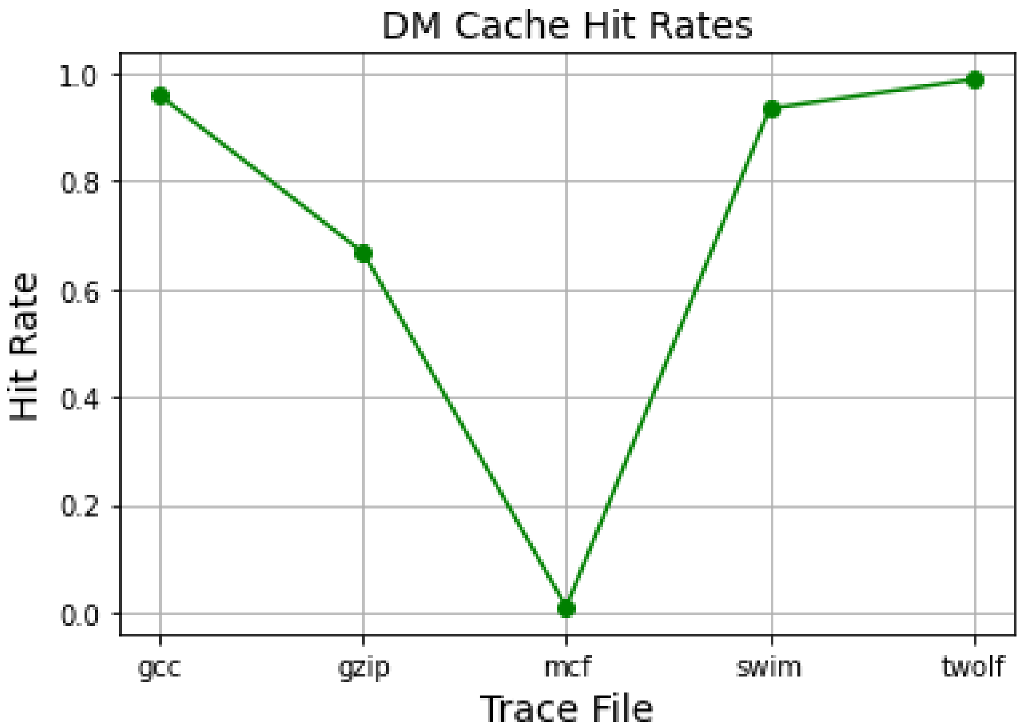
[3]:
```
%matplotlib inline
```

Let's take the values found after executing the python files

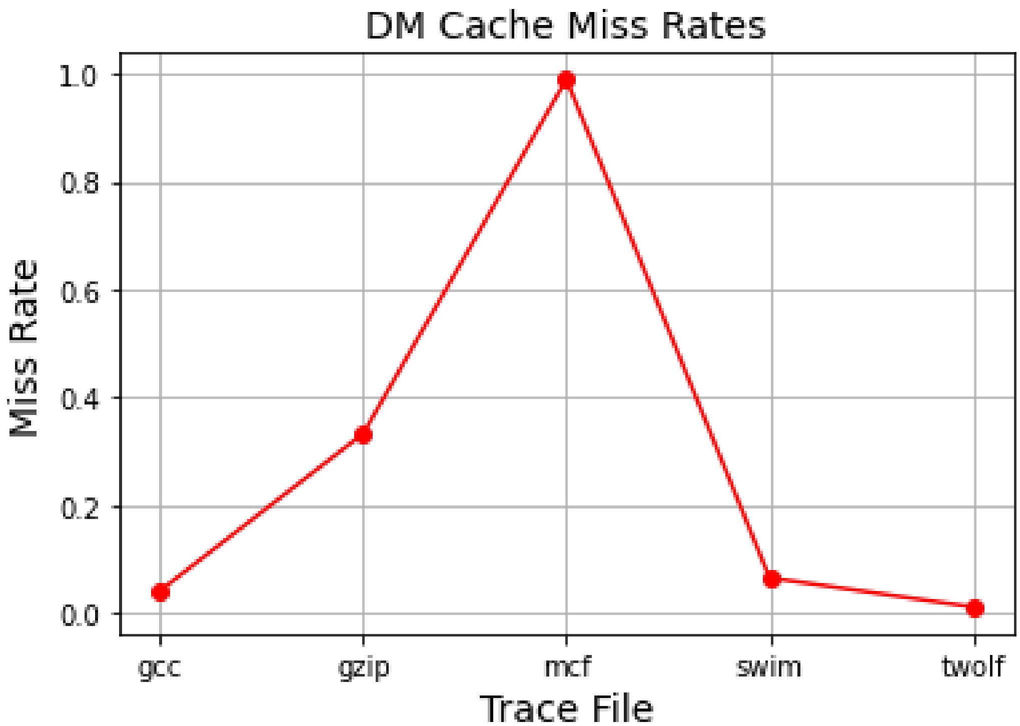
[4]:
```
names_of_trace_files = ['gcc','gzip','mcf','swim','twolf']

dm_cache_hit_rates = [0.958346503569053,0.6670720349905622,0.
 ↪010379109772699147,0.9343190640944876,0.988442993720279]
dm_cache_miss_rates = [(1 - x) for x in dm_cache_hit_rates]
dm_cache_hitmiss_ratio = [23.007588454376165,2.00365275705107,0.
 ↪010487965518103829,14.225118007431957,85.52759856630824]

sa_cache_hit_rates = [0.9382799122716863,0.6670554044952229,0.
 ↪010325481622045295,0.9262252096849202,0.9876145344887578]
sa_cache_miss_rates = [(1 - x) for x in sa_cache_hit_rates]
sa_cache_hitmiss_ratio = [15.202180470026391,2.003502725382584,0.
 ↪010433209535361618,12.554765736766809,79.73979933110368]
```

Let's plot these values for the DM Cache

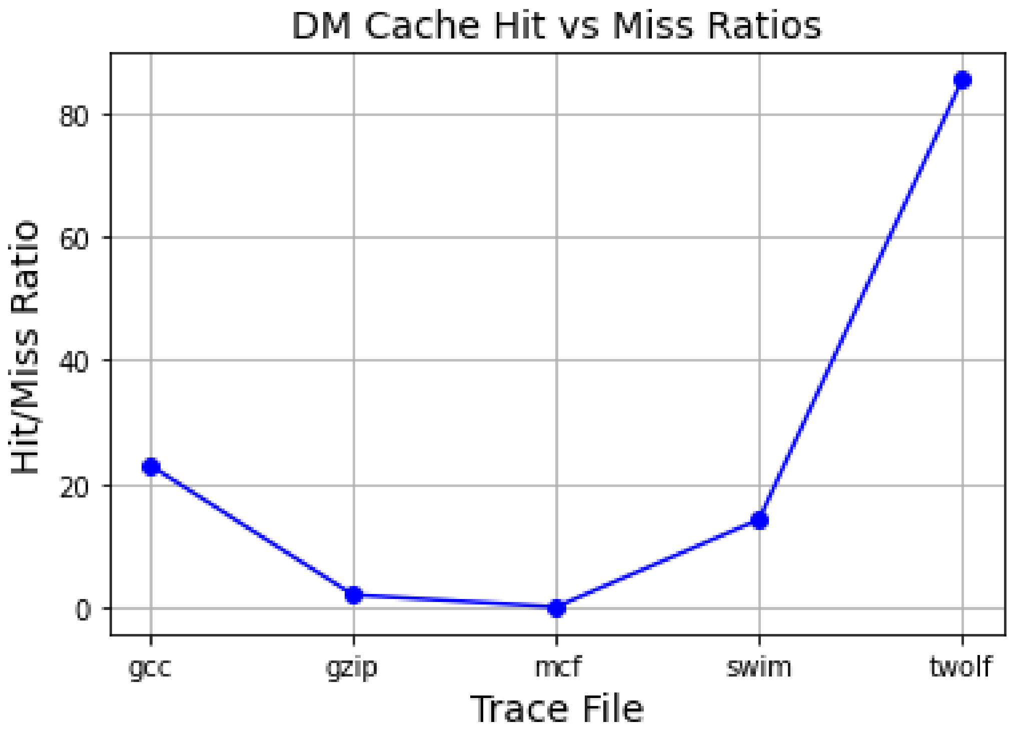
[5]:
```
plt.plot(names_of_trace_files, dm_cache_hit_rates, color='green', marker='o')
plt.title('DM Cache Hit Rates', fontsize=14)
plt.xlabel('Trace File', fontsize=14)
plt.ylabel('Hit Rate', fontsize=14)
plt.grid(True)
plt.show()
```



[6]:
```
plt.plot(names_of_trace_files, dm_cache_miss_rates, color='red', marker='o')
plt.title('DM Cache Miss Rates', fontsize=14)
plt.xlabel('Trace File', fontsize=14)
plt.ylabel('Miss Rate', fontsize=14)
plt.grid(True)
plt.show()
```



[7]:
```
plt.plot(names_of_trace_files, dm_cache_hitmiss_ratio, color='blue', marker='o')
plt.title('DM Cache Hit vs Miss Ratios', fontsize=14)
plt.xlabel('Trace File', fontsize=14)
plt.ylabel('Hit/Miss Ratio', fontsize=14)
plt.grid(True)
plt.show()
```



Observations: We see that the DM Cache does pretty well for `gcc,swim and twolf`, each having a hit rate above 90%.
It is abysmal, however, for `mcf`.
We see that it has the best accuracy for `twolf`, when measured by any metric. This effect is most profound in the dm cache hit/miss ratios graph

Let's proceed to the SA Cache implementation Before we proceed to the graphs, let's take a closer look at the replacement algorithm.

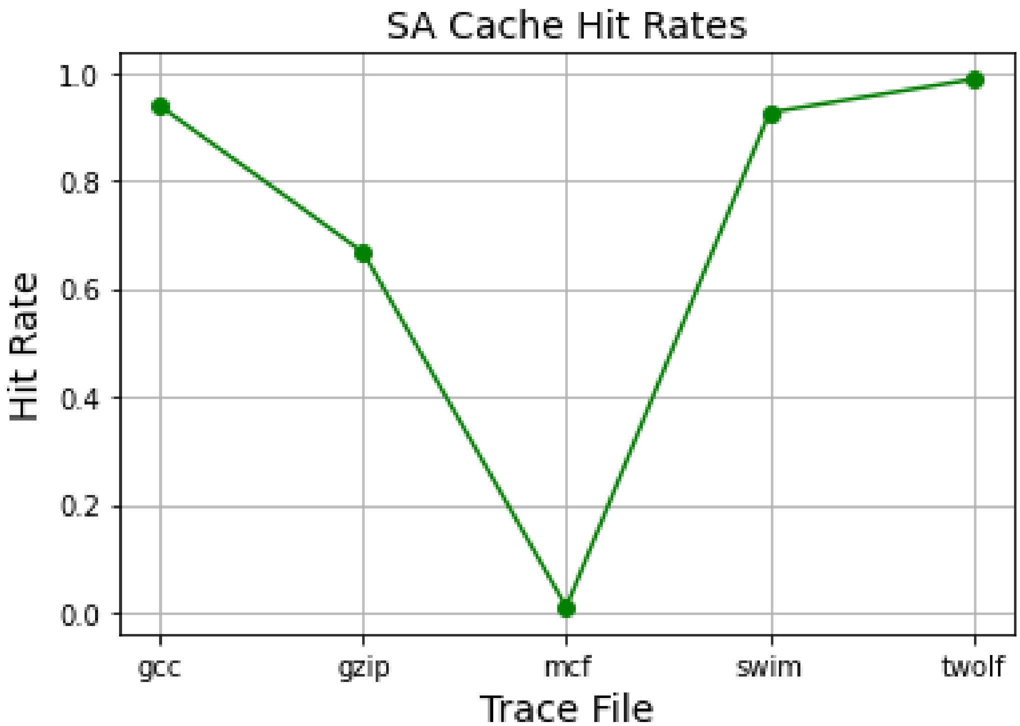
[8]:
```
def updateCache(addr):
        l = sortTheAddress(addr)
        tag = l[0] # Gets the tag bits of the given address
        decimalIndex = l[1] # Gets the integer index of the given address
        listOfWays = indexLists[decimalIndex] # Gets the list of ways at that␣
↪index

        # We check for a hit, by iterating through the ways and checking for␣
↪tag match and valid bit set
        for i in range(numberOfWays):
            originalTag = listOfWays[i].getTag()
            val = listOfWays[i].getValid()
            if originalTag == tag and val == 1: #Tag match and valid set check
```

```
                numHits+=1
                return
        # If not matched, we seek to evict the first 'empty' entry : The FIFO␣
↪policy
        for i in range(numberOfWays):
            originalTag = listOfWays[i].getTag()
            val = listOfWays[i].getValid()
            if originalTag == None or val == 0: # The empty entry
                numMiss+=1
                indexLists[decimalIndex][i].setTag(tag) # Updating that entry
                indexLists[decimalIndex][i].setValid(1)
                return
        # Else, if none of these cases hold i.e All are filled, we evict and␣
↪replace the first way as it was the first in.
        self._indexLists[decimalIndex][0].setTag(tag)
        self._indexLists[decimalIndex][0].setValid(1)
        self._numMiss += 1
```

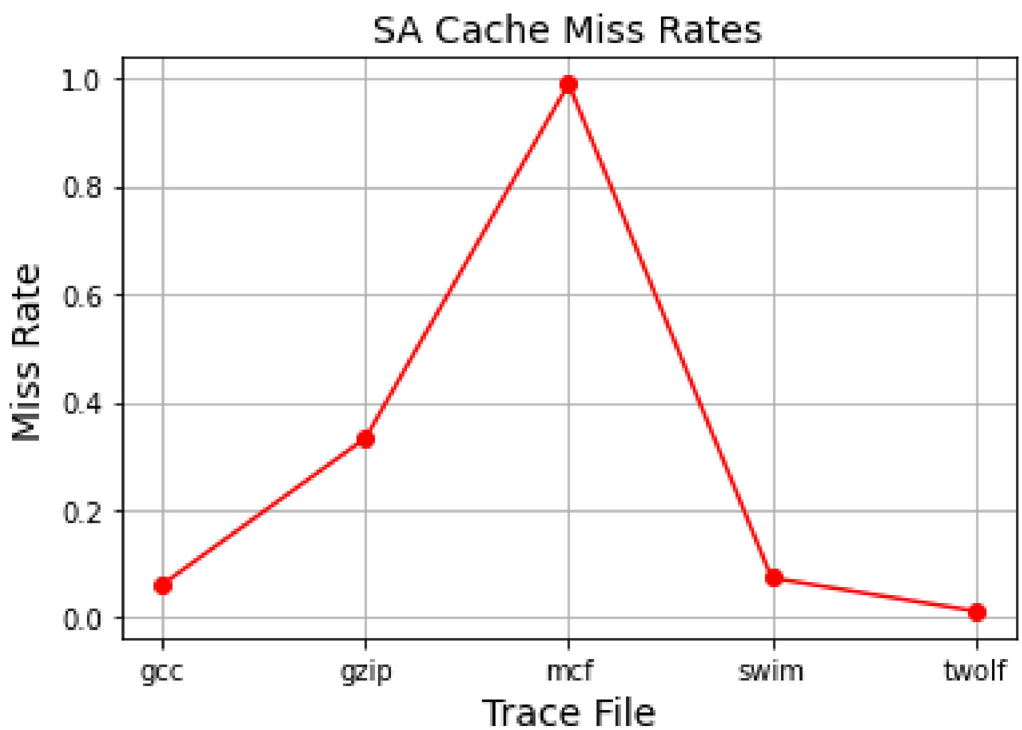
So, we see that this is a FIFO Cache Replacement Algorithm Let's see how this stacks up against the DM Cache.

First, let's graph the standalone performance

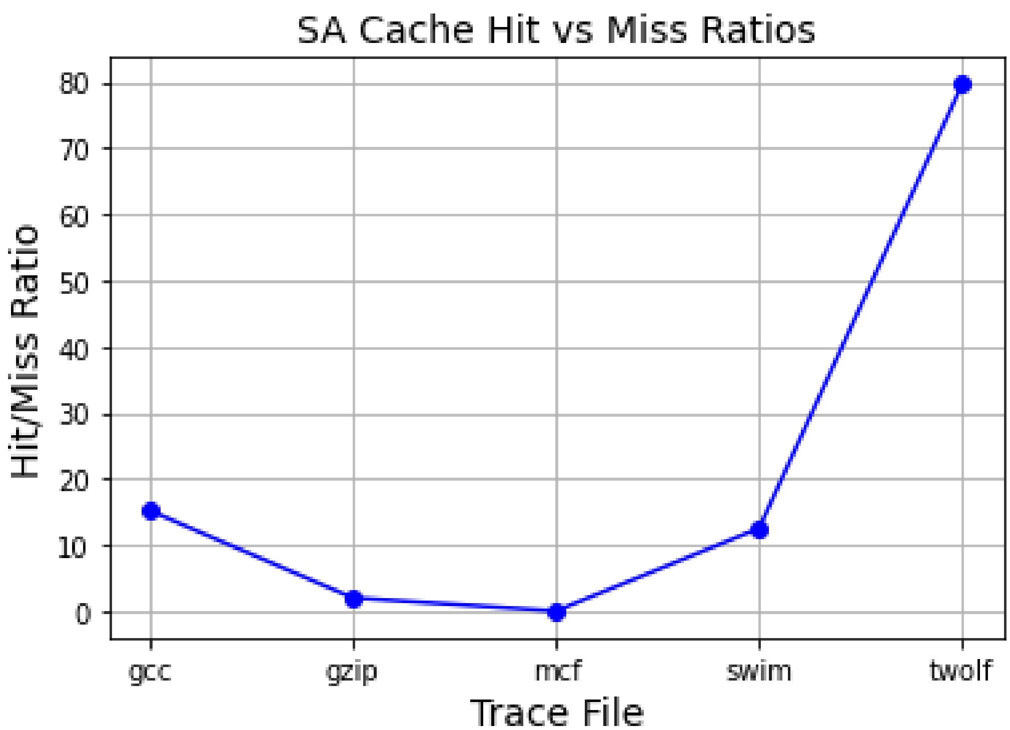
[9]:
```
plt.plot(names_of_trace_files, sa_cache_hit_rates, color='green', marker='o')
plt.title('SA Cache Hit Rates', fontsize=14)
plt.xlabel('Trace File', fontsize=14)
plt.ylabel('Hit Rate', fontsize=14)
plt.grid(True)
plt.show()
```



[10]:
```
plt.plot(names_of_trace_files, sa_cache_miss_rates, color='red', marker='o')
plt.title('SA Cache Miss Rates', fontsize=14)
plt.xlabel('Trace File', fontsize=14)
plt.ylabel('Miss Rate', fontsize=14)
plt.grid(True)
plt.show()
```



[11]:
```
plt.plot(names_of_trace_files, sa_cache_hitmiss_ratio, color='blue', marker='o')
plt.title('SA Cache Hit vs Miss Ratios', fontsize=14)
plt.xlabel('Trace File', fontsize=14)
plt.ylabel('Hit/Miss Ratio', fontsize=14)
plt.grid(True)
plt.show()
```



Observations: We see that the SA Cache, just like the DM cache, does pretty well for `gcc,swim and twolf`, each having a hit rate above 90%.
It is again abysmal for `mcf`.
We see that it has the best accuracy for `twolf`, when measured by any metric. This effect is most profound in the dm cache hit/miss ratios graph. The difference is *even more pronounced* here

Let's now compare the SA and DM caches First, let's compare average values

[12]:
```
import numpy as np
def get_average_value_of_a_list(l):
    array = np.array(l)
    return np.mean(array)
```

[13]:
```
dm_hit = get_average_value_of_a_list(dm_cache_hit_rates)
dm_miss = get_average_value_of_a_list(dm_cache_miss_rates)
dm_hm = get_average_value_of_a_list(dm_cache_hitmiss_ratio)

sa_hit = get_average_value_of_a_list(sa_cache_hit_rates)
sa_miss = get_average_value_of_a_list(sa_cache_miss_rates)
sa_hm = get_average_value_of_a_list(sa_cache_hitmiss_ratio)
```

[14]:
```
dm_hit
```

[14]: 0.7117119412294162

[15]:
```
sa_hit
```

[15]: 0.7059001085125265

We see that the DM cache performs better than SA cache in terms of hit rate, and obviously miss rate too (on average)

[16]:
```
dm_hm
```

[16]: 24.95488915013711

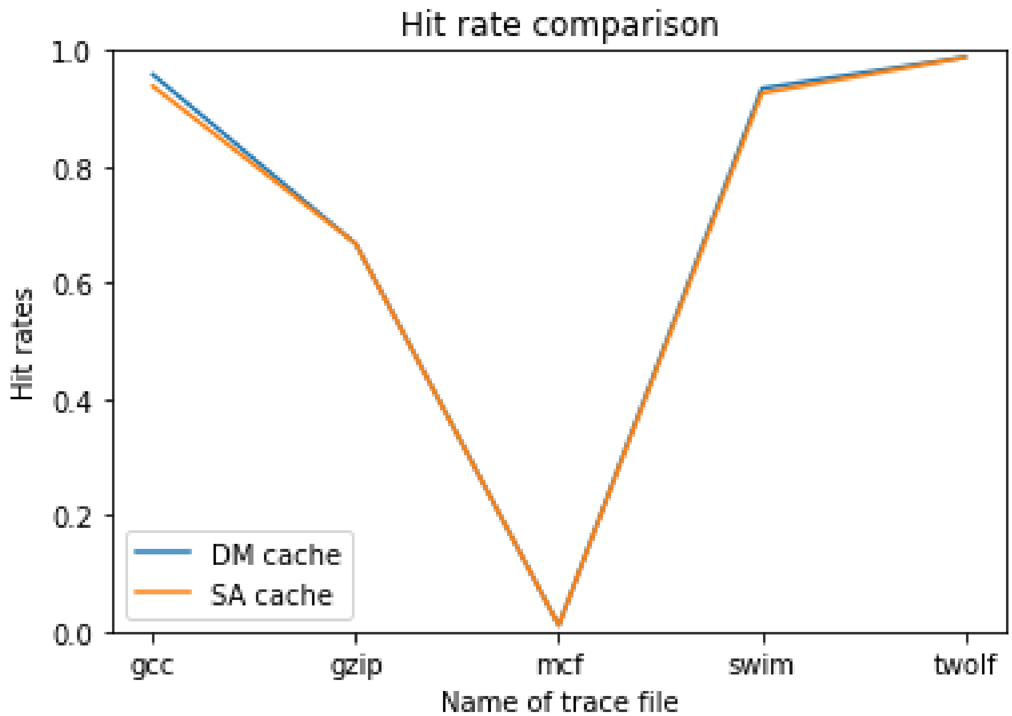
[17]:
```
sa_hm
```

[17]: 21.90213629456297

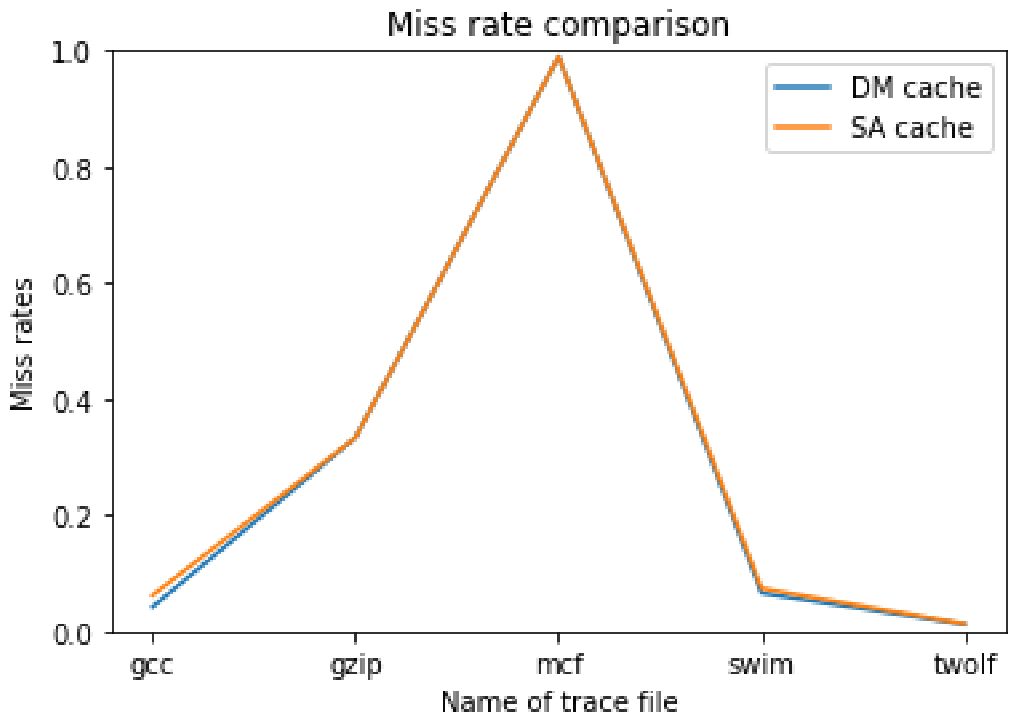
We see that the DM cache performs better than SA cache in terms of hit/miss ratio too(on average)

Let's now plot the graphs for both of the caches

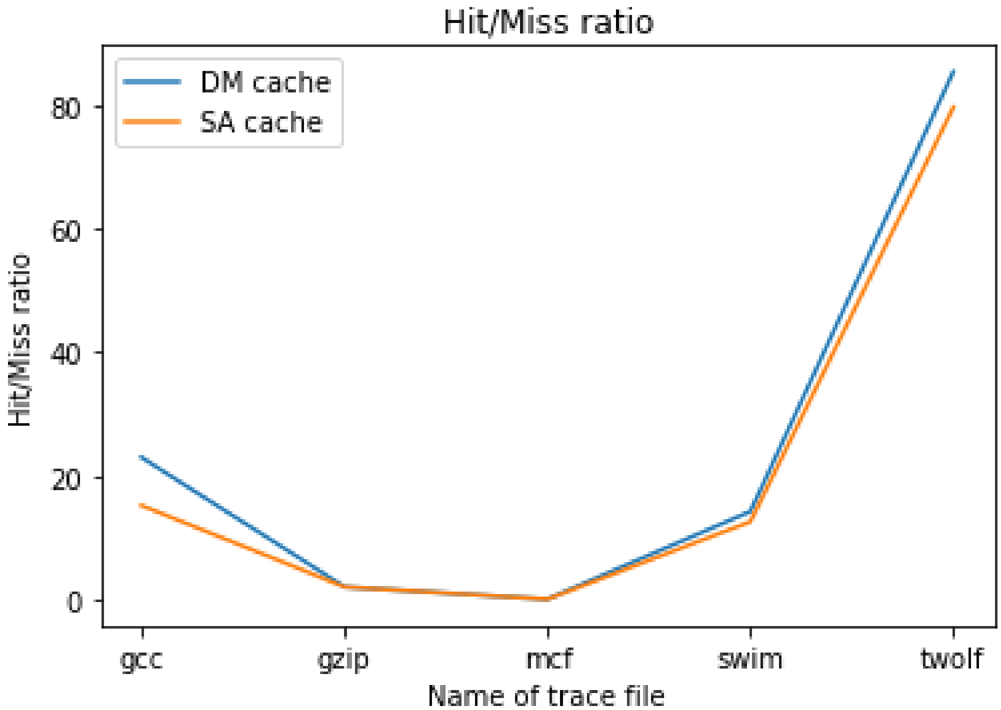
[20]:
```
x1 = names_of_trace_files
y1 = dm_cache_hit_rates
plt.plot(x1, y1, label = "DM cache")
x2 = names_of_trace_files
y2 = sa_cache_hit_rates
plt.plot(x2, y2, label = "SA cache")
plt.xlabel('Name of trace file')
plt.ylabel('Hit rates')
plt.title('Hit rate comparison')
plt.legend()
plt.ylim(0.0, 1.0)
plt.show()
```



[21]:
```
x1 = names_of_trace_files
y1 = dm_cache_miss_rates
plt.plot(x1, y1, label = "DM cache")
x2 = names_of_trace_files
y2 = sa_cache_miss_rates
plt.plot(x2, y2, label = "SA cache")
plt.xlabel('Name of trace file')
plt.ylabel('Miss rates')
plt.title('Miss rate comparison')
plt.legend()
plt.ylim(0.0, 1.0)
plt.show()
```



[24]:
```
x1 = names_of_trace_files
y1 = dm_cache_hitmiss_ratio
plt.plot(x1, y1, label = "DM cache")
x2 = names_of_trace_files
y2 = sa_cache_hitmiss_ratio
plt.plot(x2, y2, label = "SA cache")
plt.xlabel('Name of trace file')
plt.ylabel('Hit/Miss ratio')
plt.title('Hit/Miss ratio')
plt.legend()
plt.show()
```



Observations:

- We see that DM cache has a higher hit rate, lower miss rate and higher hit/miss ratio than SA cache with FIFO policy
- We need to improve our algorithm for SA cache; round robin and fifo do not cut it
- Both perform poorly for mcf trace file

```
[ ]:
```