

Set-Associative Cache Performance and Simulator

CSCE230301 - Comp Org. and Assembly Language Programming - Summer 2022

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## 1. Experiment and Design

The purpose of this project is to analyze and form conclusions and inferences about set associative cache performance based on the cache simulator we created. This is done by simulating different combinations of caches. The first experiment required us to set the number of ways to 4 and vary the cache line size to see how the hit ratio changes as we increase the cache line size. The second experiment was about controlling the line size by setting it to 16 bytes and varying the number of ways to see its correlation to the hit ratio. For both experiments we will be using six different memory reference generators and examining how and why their results differ from one another.

The first step to this project was to finish the classes directly associated with the simulator and that included setAssociativeCache and cacheLine and the functions they are used for: search and insert.

The cacheLine contained attributes of the cache line including its validity state, a counter used for the replacement policy (least frequently used), and the tag.

The setAssociativeCache class declares and sets all other information related to the cache including the line size, block address, number of ways, set number, byte offset, and set offset. It also creates the cache by filling the cache 2d vector with empty cache lines.

The search function takes in an address and checks whether there is an existent cache line containing this address by checking its validity and tag.

The insert function follows the least frequently used method to insert a new cache line. It starts by checking if there are any invalid lines and it inserts it there by incrementing the counter, changing its validity and tag. If there are no available lines then it follows the replacement policy by iterating through the cache lines and finding the one with the highest counter (least frequently used) and replacing it with the new line we want to add.

The cachSim function calls the search and insert functions to return whether the address provided is a hit or miss. This function is called in the main in a loop over all the 1000000 iterations. Inside the loop it counts all the hits and misses so that it can calculate and output their respective ratios outside the loop

## 2. Methodology

### a. Variables:

#### Experiment #1:

**Independent variable:** for the first experiment, we are changing the cache line size in factors of 2 starting with line size 16 up to 128. The unit it's represented in is bytes.

**Dependent variable:** the variable we are recording data for is the hit ratio to see how it behaves alongside the changes to the cache line size. This is calculated using the functions in our set-associative cache class.

**Control variable:** we are keeping the number of ways at 4 during the entire experiment to ensure that nothing other than the line size changes the hit ratio.

#### Experiment #2:

**Independent variable:** we are doing the opposite in this experiment where we are making the number of ways the IV, starting with 1 until 8 and increasing with factors of 2: 1, 2, 4, 8.

**Dependent variable:** just like experiment 1, we are seeing how the hit ratio changes according to the number of ways. That is the premise of this project: it's how we measure the performance of the cache.

**Control variable:** we are keeping the cache line constant to 16 bytes.

### 3. Results and Analysis

#### a. Raw Data:

Check Appendix #1 for screenshots of each output

##### i. Experiment #1:

memgen1				
line size (bytes)	# of hits	# of misses	hit ratio	Miss ratio
16	937,500	62500	93.75	6.25
32	968,750	31250	96.875	3.125
64	984,375	15625	98.4375	1.5625
128	992,187	7813	99.2187	0.7813

memgen2				
line size (bytes)	# of hits	# of misses	hit ratio	Miss ratio
16	998,464	1536	99.8464	0.1536
32	999,232	768	99.9232	0.0768
64	999,616	384	99.9616	0.0384
128	999,808	192	99.9808	0.0192

memgen3				
line size (bytes)	# of hits	# of misses	hit ratio	Miss ratio
16	968	999,032	0.0968	99.9032
32	987	999,013	0.0987	99.9013
64	966	999,034	0.0966	99.9034
128	983	999,017	0.0983	99.9017

memgen4				
line size (bytes)	# of hits	# of misses	hit ratio	Miss ratio
16	999,744	256	99.9744	0.0256
32	999,872	128	99.9872	0.0128
64	999,936	64	99.9936	0.0064
128	999,968	32	99.9968	0.0032

memgen5				
line size (bytes)	# of hits	# of misses	hit ratio	Miss ratio
16	995,904	4096	99.5904	0.4096
32	997,952	2048	99.7952	0.2048
64	998,976	1024	99.8976	0.1024
128	999,488	512	99.9488	0.0512

memgen6				
line size (bytes)	# of hits	# of misses	hit ratio	Miss ratio
16	185,920	814,080	18.592	81.4080
32	185,920	814,080	18.592	81.4080
64	592,960	407,040	59.296	40.7040
128	796,480	203,520	79.648	20.3520

ii. Experiment #2:

memgen1				
no of ways	# of hits	# of misses	hit ratio	Miss ratio
1	937,500	62500	93.75	6.25
2	937,500	62500	93.75	6.25
4	937,500	62500	93.75	6.25
8	937,500	62500	93.75	6.25

memgen2				
no of ways	# of hits	# of misses	hit ratio	Miss ratio
1	998,464	1536	99.8464	0.1536
2	998,464	1536	99.8464	0.1536
4	998,464	1536	99.8464	0.1536
8	998,464	1536	99.8464	0.1536

memgen3				
no of ways	# of hits	# of misses	hit ratio	Miss ratio
1	1021	998,979	0.1021	99.8979
2	1007	998,993	0.1007	99.8993
4	968	999,032	0.0968	99.9032
8	1000	999,000	0.1	99.9

memgen4				
no of ways	# of hits	# of misses	hit ratio	Miss ratio
1	999,744	256	99.9744	0.0256
2	999,744	256	99.9744	0.0256
4	999,744	256	99.9744	0.0256
8	999,744	256	99.9744	0.0256

memgen5				
no of ways	# of hits	# of misses	hit ratio	Miss ratio
1	995,904	4096	99.5904	0.4096
2	995,904	4096	99.5904	0.4096
4	995,904	4096	99.5904	0.4096
8	995,904	4096	99.5904	0.4096

memgen6				
no of ways	# of hits	# of misses	hit ratio	Miss ratio
1	0	1,000,000	0	100
2	123,904	876,096	12.3904	87.6096
4	18,5920	814,080	18.592	81,4080
8	21,7152	782,848	21.7152	782,848

### b. Processed Data:

Experiment #1					
memgen1		memgen2		memgen3	
line size (bytes)	hit ratio	line size (bytes)	hit ratio	line size (bytes)	hit ratio
16	93.75	16	99.8464	16	0.0968
32	96.675	32	99.9232	32	0.0987
64	98.4375	64	99.9616	64	0.0966
128	99.2187	128	99.9808	128	0.0983

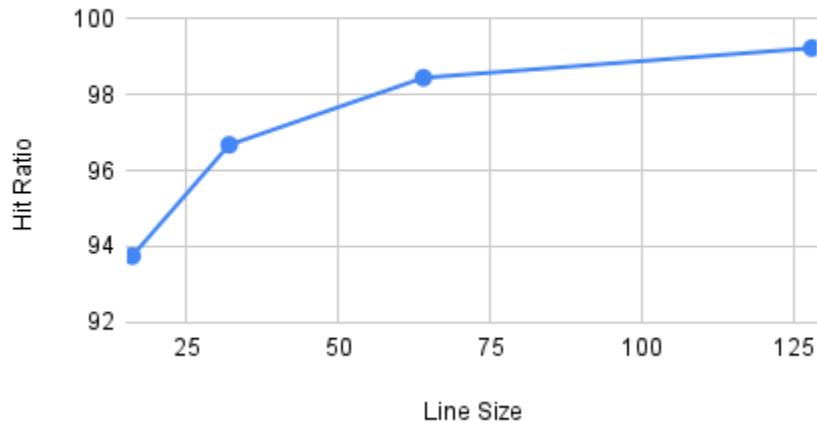
Experiment #1					
memgen4		memgen5		memgen6	
line size (bytes)	hit ratio	line size (bytes)	hit ratio	line size (bytes)	hit ratio
16	99.9744	16	99.5904	16	18.592
32	99.9872	32	99.7952	32	18.592
64	99.9936	64	99.8976	64	59.296
128	99.9968	128	99.9488	128	79.648

Experiment #2					
memgen1		memgen2		memgen3	
no of ways	hit ratio	no of ways	hit ratio	no of ways	hit ratio
1	93.75	1	99.8464	1	0.1021
2	93.75	2	99.8464	2	0.1007
4	93.75	4	99.8464	4	0.0968
8	93.75	8	99.8464	8	0.1

Experiment #2					
memgen4		memgen5		memgen6	
no of ways	hit ratio	no of ways	hit ratio	no of ways	hit ratio
1	99.9744	1	99.5904	1	0
2	99.9744	2	99.5904	2	12.3904
4	99.9744	4	99.5904	4	18.592
8	99.9744	8	99.5904	8	21.7152

c. Graphs:

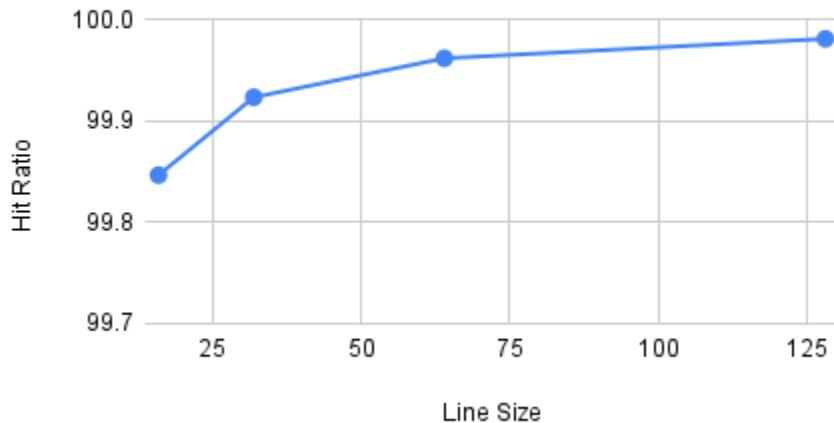
Hit Ratio vs. Line Size for memGen1



**Figure 1.** Graph for the data of the line size vs hit ratio, keeping the number of ways 4 using memgen1()

Since we are increasing the line size we now make use of spatial locality. As such, increasing the line size increases the hit ratio, however it starts to level off after line size 64 Bytes.

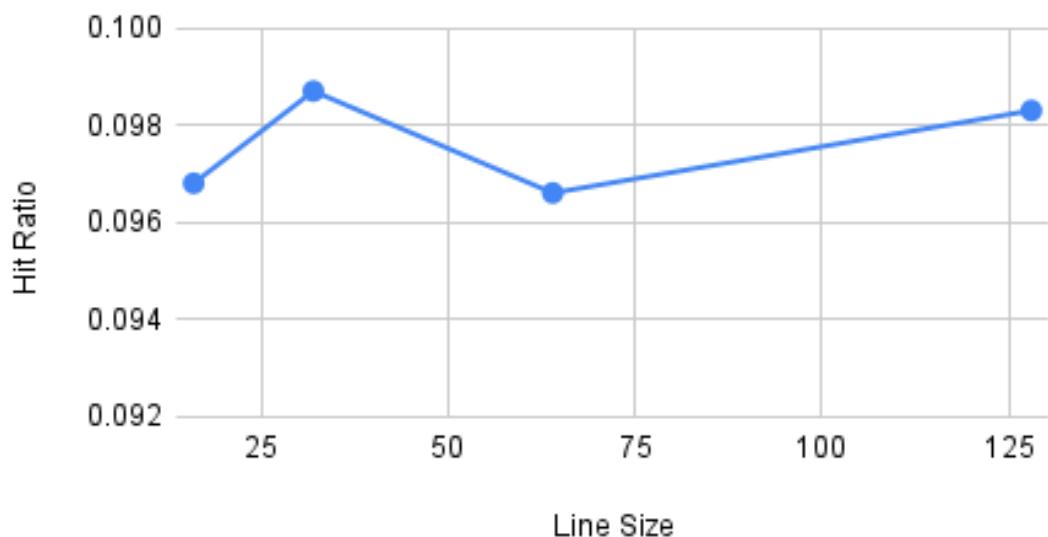
Hit Ratio vs. Line Size for memGen2



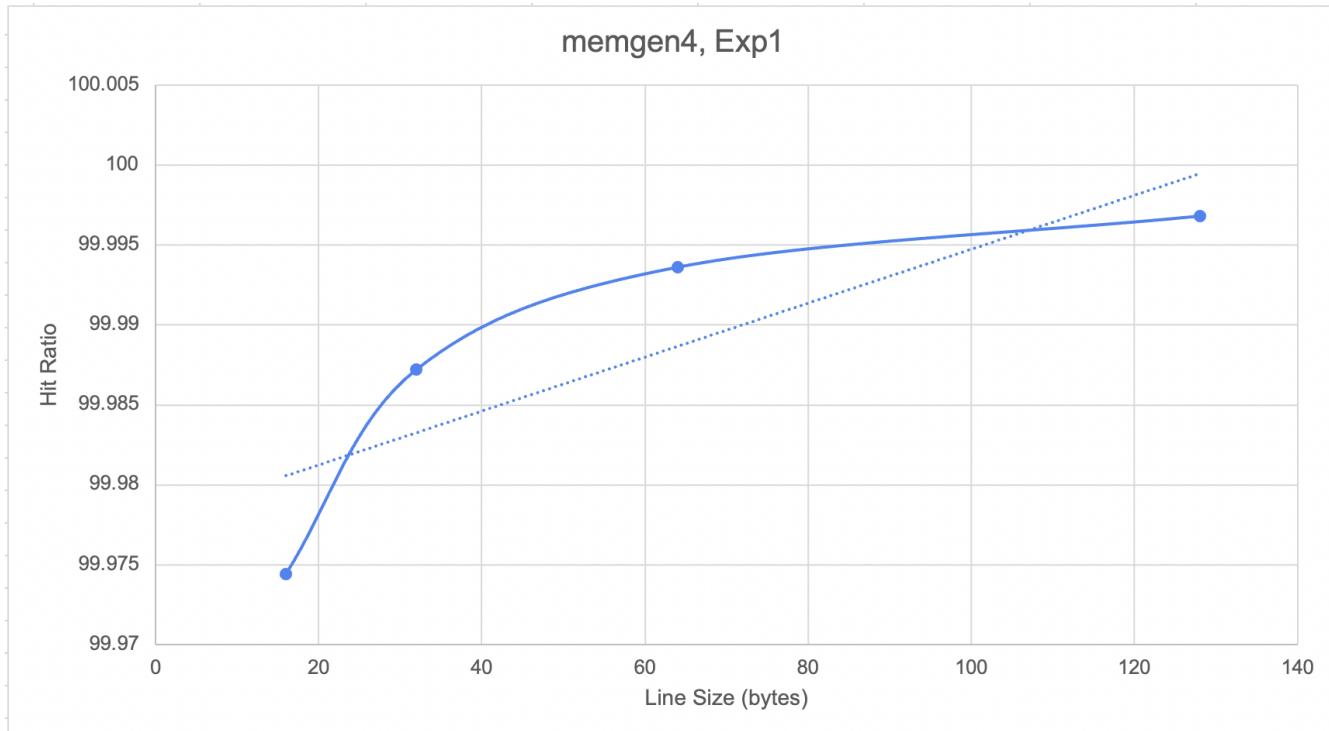
**Figure 2.** Graph for the data of the line size vs hit ratio, keeping the number of ways 4 using memgen2()

Memgen2 generates a random address. As we increase the line size we make sure of spatial locality and thus the hit ratio increases with line size. It however starts to level off after 64 Bytes for line size as compulsory misses are not avoidable.

### Hit Ratio vs. Line Size for memGen3

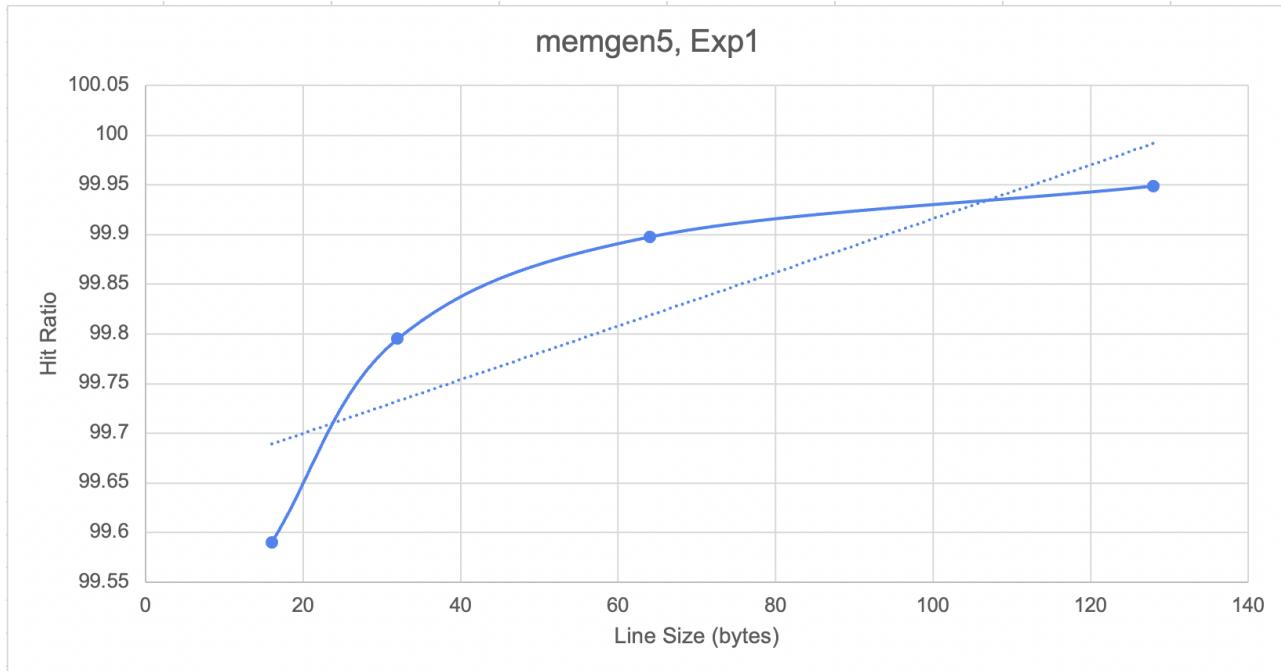


**Figure 3.** Graph for the data of the line size vs hit ratio, keeping the number of ways 4 using memgen3()  
memGen3 generates much larger random addresses, as such the number of compulsory misses will be high. Increasing line size makes use of spatial locality. Since this is a random function, spatial locality does not really matter here and that's why we see very minimal differences between the hit ratio across all line sizes.



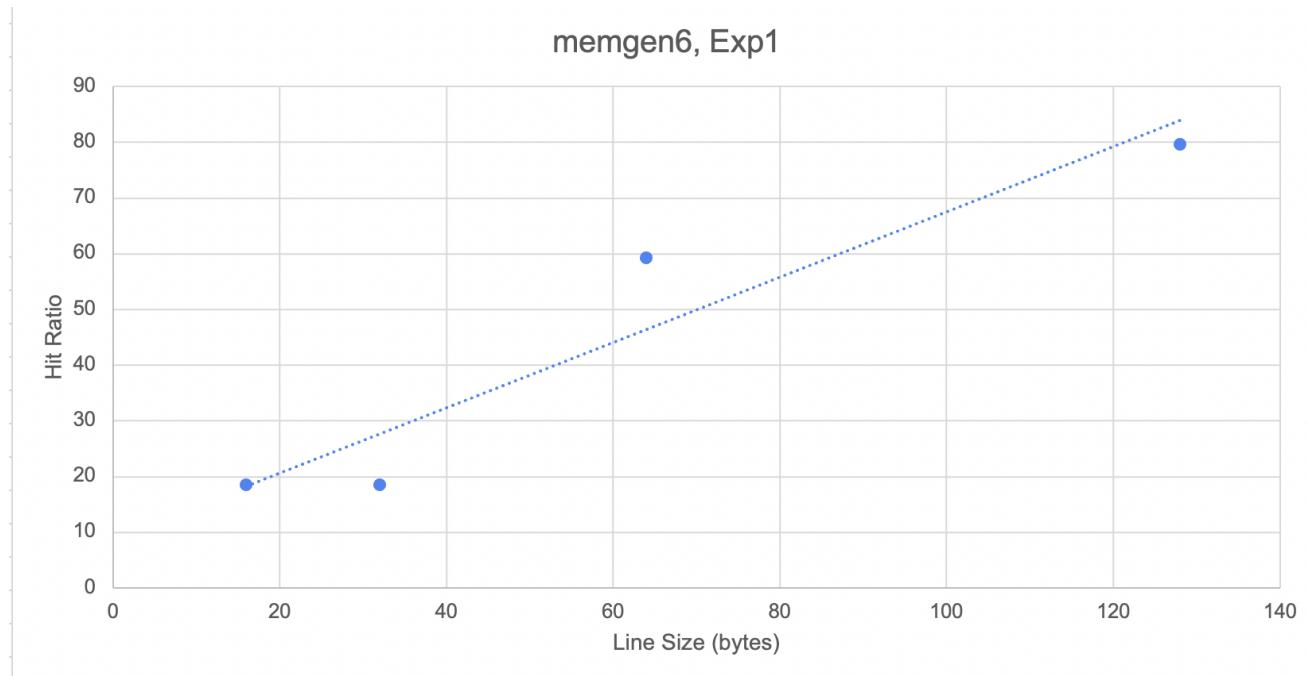
**Figure 4.** Graph representing the line size vs hit ratio with the # of ways 4 using memgen4()

This is a zoomed in view of the graph showing only the values of the hit ratio from 99.97 to 100.005 because this function generated values very close to each other with all of them having high hit ratios. Line size 16 bytes has a hit ratio of 99.9744 and it increases with small increments as we increase the line size. If we look at the number of misses available in the raw data, we will see that the miss ratio decreases from 256 to 32 in factors of 2. The increase that happens between the line size is due to the utilization of spatial locality as more memory addresses could be fetched in a single block at a time. As for the incrementation of change, it's the same across different values for the number of iterations and so it can be attributed to the number we are modulusng and not the address/number of iterations we are incrementing. The function goes as follow where addr goes from 0 to the number of iterations: return (addr++)%(4\*1024). This means that the output ranges from 0 to 4096. Therefore the number of misses should stay constant for number of iterations from 4096 upwards. If we tabulated the TAG and Index of this sequencing of addresses for each cache line size we will see that the 4-way set-associative cache changes in this manner in accordance with the memory generation.



**Figure 5.** Graph representing the line size vs hit ratio with the # of ways 4 using memgen5()

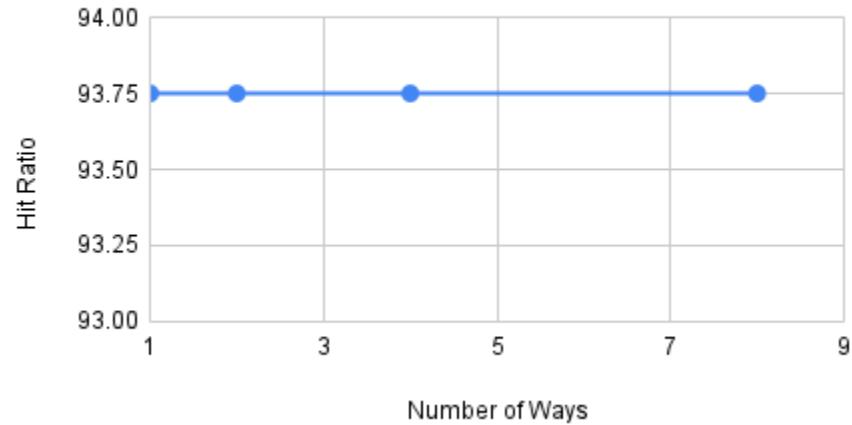
This graph behaves very similarly to the previous one with the only difference being that the miss ratio ranges from 4096 to 512. This behavior makes sense because it's the same function but instead of the addresses ranging from 0 to 4095 they range from 0 to 65535 where 65536 is 16 times 4095 and so is the range of misses. For memgen4() line size 16 the number of misses is 256 and for memgen5() the number of misses is  $256 \times 16 = 4096$ , this formula applies to the three other line sizes. The reasoning behind this trend is the same as the previous one.



**Figure 6.** Graph for the data of the line size vs hit ratio, keeping the number of ways 4 using memgen6()

Just like the previous graphs, the upward increasing trendline is due to the utilization of spatial locality. As for a lower starting hit ratio that would be because of the bits allocated to index and how we are incrementing the addresses: adding 32 instead of 1. Leading to different indices and a higher miss rate. Having the ratio fixed for line sizes 16 and 32 can be attributed to the difference not being large enough to impact the distribution of the tag and index along a 4 way set. The spatial locality only becomes effective once it hits the 64 byte line size.

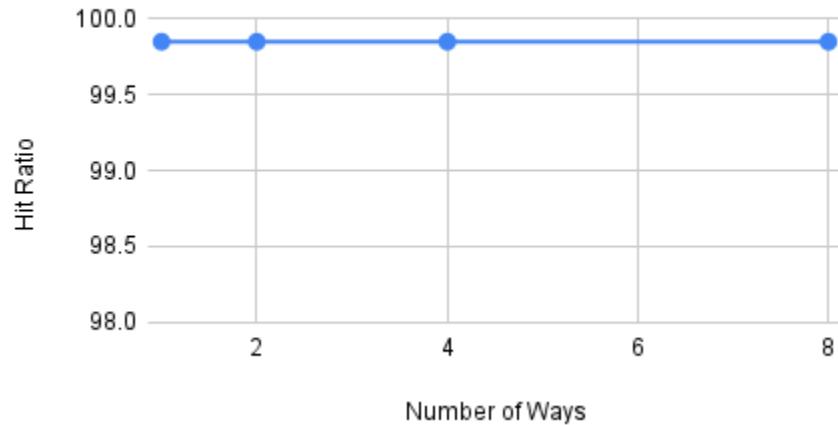
**Hit Ratio vs. Number of Ways for menGen1**



**Figure 7.** Graph demonstrating the # of ways vs Hit Ratio using memgen1() and 16 bytes for the cache line

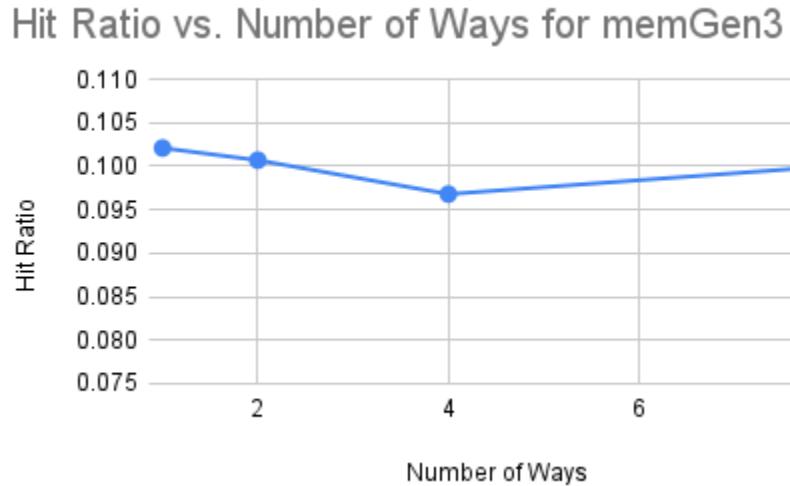
The hit ratio stayed the same in Experiment 2 as we increased the number of ways and kept the line size constant at 16. MemGen1 generated consequent addresses, as such it made full use of spatial locality. When we increase the number of ways, we decrease the number of sets, however we can store more addresses per set and since they are consequent, we will have only compulsory misses in both cases.

**Hit Ratio vs. Number of Ways for memGen2**



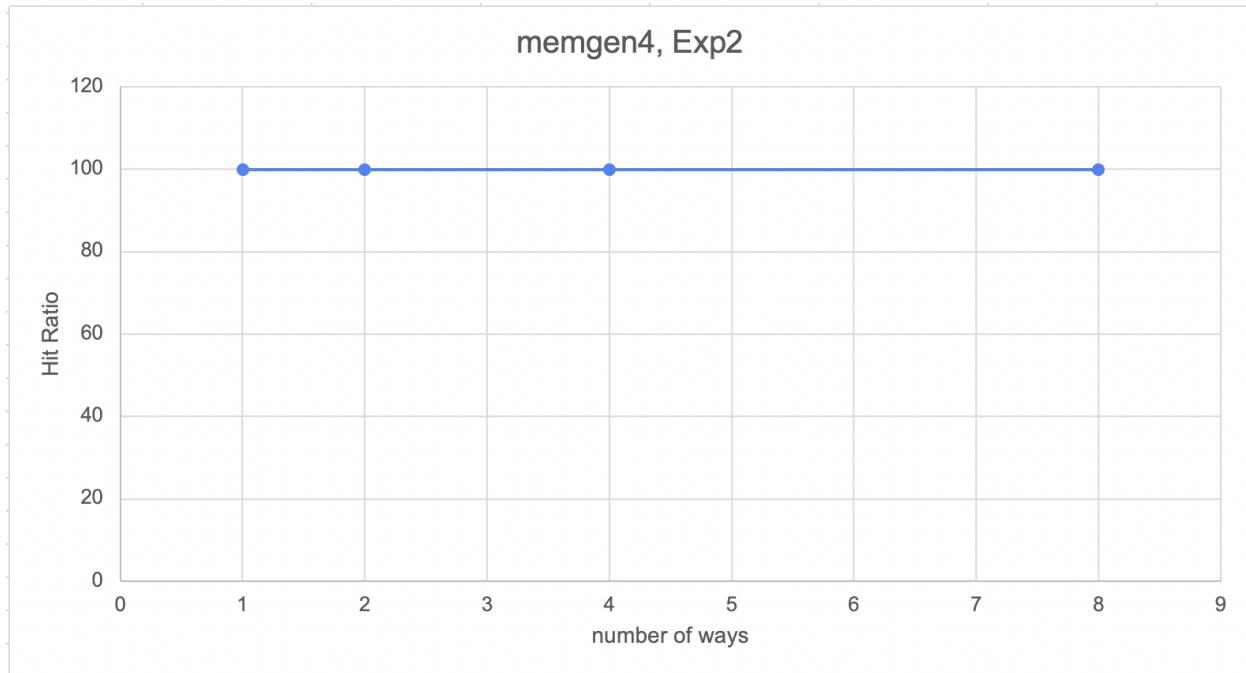
**Figure 8.** Graph demonstrating the # of ways vs Hit Ratio using memgen2() and 16 bytes for the cache line

As the number of ways increases, conflict misses decrease. However, since memgen2 produces random numbers, there is a very slim chance of conflict misses occurring, as such we have the same hit rates for 1, 2, 4 and 8 way set associative caches.



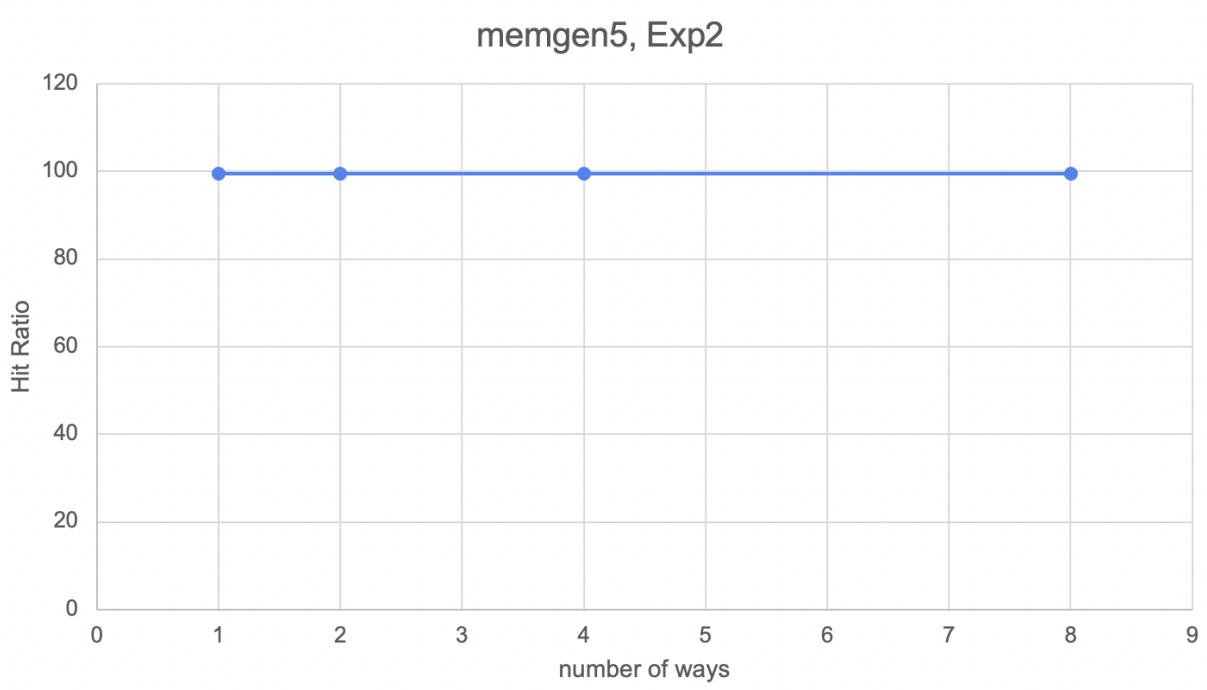
**Figure 9.** Graph demonstrating the # of ways vs Hit Ratio using memgen3() and 16 bytes for the cache line

memGen3() uses randomly generated addresses which causes the hit ratio to be slightly unpredictable. This is the reason it is decreasing then increasing as we move across the number of ways; however the difference between the values is negligible. The main reason for this is because the program didn't make use of the spatial locality due to the fact that it was randomly generated.



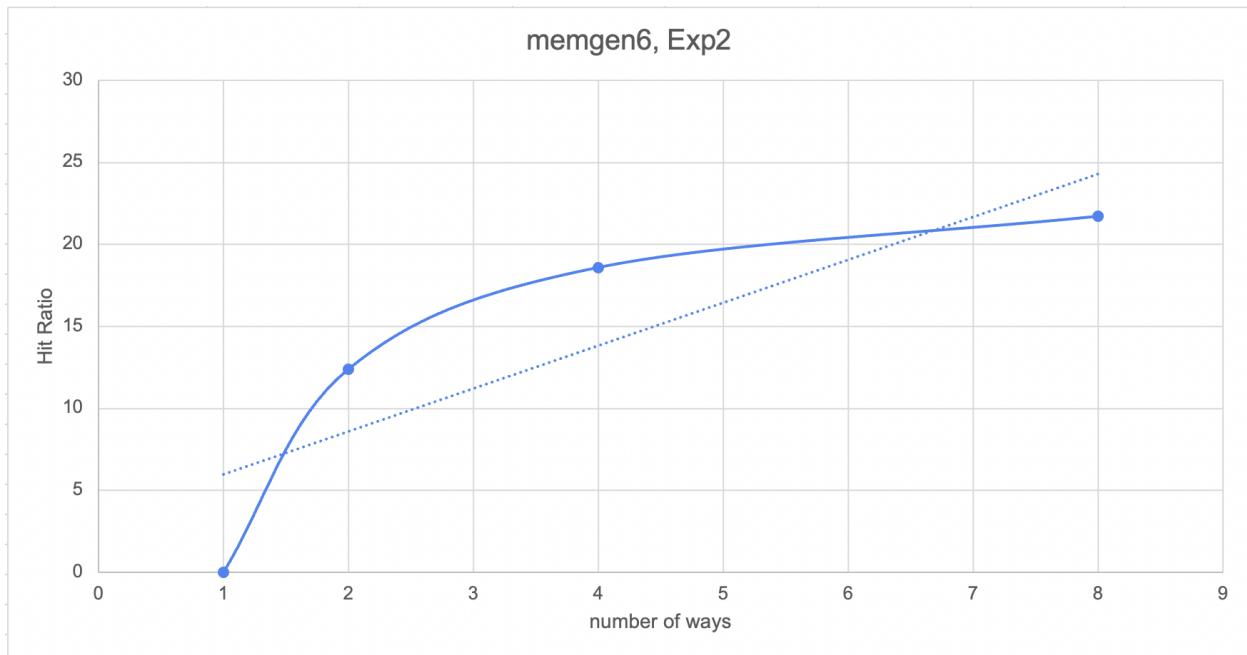
**Figure 10.** Graph for the # of ways vs Hit Ratio using memgen4() and keeping the cache line size to 16 bytes

The hit ratio was near perfect and the same for all 4 ways. The high hit ratio was due to the nature of how the addresses were incremented and looped, just like in memgen4() in experiment 1. Increasing the number of ways increases the number of blocks per set and thus more memory addresses can be cached into the same index which should result in a higher hit ratio. However, in this case, this memory generator generates memory addresses that do not utilize having more than one block per set. It could simply be due to only one block per set being utilized and the tags never mismatching—leading to a lack of need to save in another block.



**Figure 11.** Graph for the # of ways vs Hit ratio, using memgen5() and 16 bytes for the cache line

The explanation and reasoning behind this is just as the previous one because it's the same function with only the number we are modulus using it with is scaled by 16 and so is the number of misses—just as discussed in experiment #1.



**Figure 12.** Graph demonstrating the # of ways vs Hit Ratio using memgen6() and 16 bytes for the cache line

The data collected from memgen6 shows that the hit ratio increases by increasing the associativity. The reasoning behind this is that increasing the number of ways increases the number of blocks per set and thus more memory addresses can be cached into the same index which results in a higher hit ratio. This wasn't the case for memgen4 and 5 because of how addr was incremented. The sequencing of sequential addresses incrementing by 1 leads to a constant and high hit ratio unlike a range of addresses incrementing by a large value. Utilizing the increase in the number of blocks.

#### 4. Conclusion

We observed the expected behavior of varying line size and number of ways while keeping cache size constant. The things that affected the performance of the cache the most was the way memory addresses were generated and how they were stored in the cache. Memgen1, 4, and 5 generated sequential addresses and as such was able to make use of spatial locality the most, these simulated access of arrays. This led to high hit ratios in these experiments. Memgen2 and 3 were random number generators and as such lead to a lot of compulsory misses. These generators did not make use of spatial locality and as such the miss ratio was very high. Memgen6 generated addresses that differed by 32. This also led to poor performance as spatial locality was not utilized here. Memgen6 kind of simulates the behavior of 2D arrays in C++ that are accessed column wise first.

## 5. Appendices

### a. Appendix #1 (Output):

Experiment #1, memgen1():

```
0x000f423c (Hit)
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 16, and number of ways = 4
Number of hits = 937500
Number of misses = 62500
Hit ratio = 93.75
Miss ratio = 6.25
Program ended with exit code: 0
```

```
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 64, and number of ways = 4
Number of hits = 984375
Number of misses = 15625
Hit ratio = 98.4375
Miss ratio = 1.5625
Program ended with exit code: 0
```

```
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 128, and number of ways = 4
Number of hits = 992187
Number of misses = 7813
Hit ratio = 99.2187
Miss ratio = 0.7813
Program ended with exit code: 0
```

```
0x000011a4 (Hit)
0x000032c1 (Hit)
This is the output using memGen2, line size = 32, and number of ways = 4
Number of hits = 999232
Number of misses = 768
Hit ratio = 99.9232
Miss ratio = 0.0768
Program ended with exit code: 0
```

**Experiment #1, memgen2():**

```
0x000000004 (Hit)
0x000000a16 (Hit)
0x0000011a4 (Hit)
0x0000032c1 (Hit)
This is the output using memGen2, line size = 16, and number of ways = 4
Number of hits = 998464
Number of misses = 1536
Hit ratio = 99.8464
Miss ratio = 0.1536
Program ended with exit code: 0
```

```
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 32, and number of ways = 4
Number of hits = 968750
Number of misses = 31250
Hit ratio = 96.875
Miss ratio = 3.125
Program ended with exit code: 0
```

```
0x000000004 (Hit)
0x000000a16 (Hit)
0x0000011a4 (Hit)
0x0000032c1 (Hit)
This is the output using memGen2, line size = 64, and number of ways = 4
Number of hits = 999616
Number of misses = 384
Hit ratio = 99.9616
Miss ratio = 0.0384
Program ended with exit code: 0
```

```
0x000000a16 (Hit)
0x0000011a4 (Hit)
0x0000032c1 (Hit)
This is the output using memGen2, line size = 128, and number of ways = 4
Number of hits = 999808
Number of misses = 192
Hit ratio = 99.9808
Miss ratio = 0.0192
Program ended with exit code: 0
```

## Experiment #1: memgen3:

```
0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 16, and number of ways = 4
Number of hits = 968
Number of misses = 999032
Hit ratio = 0.0968
Miss ratio = 99.9032
Program ended with exit code: 0

0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 32, and number of ways = 4
Number of hits = 987
Number of misses = 999013
Hit ratio = 0.0987
Miss ratio = 99.9013
Program ended with exit code: 0

0x00a618a4 (Miss)
0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 64, and number of ways = 4
Number of hits = 966
Number of misses = 999034
Hit ratio = 0.0966
Miss ratio = 99.9034
Program ended with exit code: 0

0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 128, and number of ways = 4
Number of hits = 983
Number of misses = 999017
Hit ratio = 0.0983
Miss ratio = 99.9017
Program ended with exit code: 0
```

## Experiment #1, memGen4:

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 16, and number of ways = 4
Number of hits = 999744
Number of misses = 256
Hit ratio = 99.9744
Miss ratio = 0.0256
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 32, and number of ways = 4
Number of hits = 999872
Number of misses = 128
Hit ratio = 99.9872
Miss ratio = 0.0128
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 64, and number of ways = 4
Number of hits = 999936
Number of misses = 64
Hit ratio = 99.9936
Miss ratio = 0.0064
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 128, and number of ways = 4
Number of hits = 999968
Number of misses = 32
Hit ratio = 99.9968
Miss ratio = 0.0032
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

## Experiment #1, memGen5:

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000004210 (Hit)
0x000000004217 (Hit)
0x000000004218 (Hit)
0x000000004219 (Hit)
0x00000000421a (Hit)
0x00000000421b (Hit)
0x00000000421c (Hit)
0x00000000421d (Hit)
0x00000000421e (Hit)
0x00000000421f (Hit)
0x000000004220 (Hit)
0x000000004221 (Hit)
0x000000004222 (Hit)
0x000000004223 (Hit)
0x000000004224 (Hit)
0x000000004225 (Hit)
0x000000004226 (Hit)
0x000000004227 (Hit)
0x000000004228 (Hit)
0x000000004229 (Hit)
0x00000000422a (Hit)
0x00000000422b (Hit)
0x00000000422c (Hit)
0x00000000422d (Hit)
0x00000000422e (Hit)
0x00000000422f (Hit)
0x000000004230 (Hit)
0x000000004231 (Hit)
0x000000004232 (Hit)
0x000000004233 (Hit)
0x000000004234 (Hit)
0x000000004235 (Hit)
0x000000004236 (Hit)
0x000000004237 (Hit)
0x000000004238 (Hit)
0x000000004239 (Hit)
0x00000000423a (Hit)
0x00000000423b (Hit)
0x00000000423c (Hit)
0x00000000423d (Hit)
0x00000000423e (Hit)
0x00000000423f (Hit)
This is the output using memGen5, line size = 16, and number of ways = 4
Number of hits = 995904
Number of misses = 4096
Hit ratio = 99.95%
Miss ratio = 0.4096
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER Filter (e.g.

```
0x000000004210 (Hit)
0x000000004217 (Hit)
0x000000004218 (Hit)
0x000000004219 (Hit)
0x00000000421a (Hit)
0x00000000421b (Hit)
0x00000000421c (Hit)
0x00000000421d (Hit)
0x00000000421e (Hit)
0x00000000421f (Hit)
0x000000004220 (Hit)
0x000000004221 (Hit)
0x000000004222 (Hit)
0x000000004223 (Hit)
0x000000004224 (Hit)
0x000000004225 (Hit)
0x000000004226 (Hit)
0x000000004227 (Hit)
0x000000004228 (Hit)
0x000000004229 (Hit)
0x00000000422a (Hit)
0x00000000422b (Hit)
0x00000000422c (Hit)
0x00000000422d (Hit)
0x00000000422e (Hit)
0x00000000422f (Hit)
0x000000004230 (Hit)
0x000000004231 (Hit)
0x000000004232 (Hit)
0x000000004233 (Hit)
0x000000004234 (Hit)
0x000000004235 (Hit)
0x000000004236 (Hit)
0x000000004237 (Hit)
0x000000004238 (Hit)
0x000000004239 (Hit)
0x00000000423a (Hit)
0x00000000423b (Hit)
0x00000000423c (Hit)
0x00000000423d (Hit)
0x00000000423e (Hit)
0x00000000423f (Hit)
This is the output using memGen5, line size = 32, and number of ways = 4
Number of hits = 997952
Number of misses = 2048
Hit ratio = 99.97%
Miss ratio = 0.2048
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000004210 (Hit)
0x000000004217 (Hit)
0x000000004218 (Hit)
0x000000004219 (Hit)
0x00000000421a (Hit)
0x00000000421b (Hit)
0x00000000421c (Hit)
0x00000000421d (Hit)
0x00000000421e (Hit)
0x00000000421f (Hit)
0x000000004220 (Hit)
0x000000004221 (Hit)
0x000000004222 (Hit)
0x000000004223 (Hit)
0x000000004224 (Hit)
0x000000004225 (Hit)
0x000000004226 (Hit)
0x000000004227 (Hit)
0x000000004228 (Hit)
0x000000004229 (Hit)
0x00000000422a (Hit)
0x00000000422b (Hit)
0x00000000422c (Hit)
0x00000000422d (Hit)
0x00000000422e (Hit)
0x00000000422f (Hit)
0x000000004230 (Hit)
0x000000004231 (Hit)
0x000000004232 (Hit)
0x000000004233 (Hit)
0x000000004234 (Hit)
0x000000004235 (Hit)
0x000000004236 (Hit)
0x000000004237 (Hit)
0x000000004238 (Hit)
0x000000004239 (Hit)
0x00000000423a (Hit)
0x00000000423b (Hit)
0x00000000423c (Hit)
0x00000000423d (Hit)
0x00000000423e (Hit)
0x00000000423f (Hit)
This is the output using memGen5, line size = 64, and number of ways = 4
Number of hits = 998976
Number of misses = 1024
Hit ratio = 99.8976
Miss ratio = 0.1024
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000000004210 (Hit)
0x000000004217 (Hit)
0x000000004218 (Hit)
0x000000004219 (Hit)
0x00000000421a (Hit)
0x00000000421b (Hit)
0x00000000421c (Hit)
0x00000000421d (Hit)
0x00000000421e (Hit)
0x00000000421f (Hit)
0x000000004220 (Hit)
0x000000004221 (Hit)
0x000000004222 (Hit)
0x000000004223 (Hit)
0x000000004224 (Hit)
0x000000004225 (Hit)
0x000000004226 (Hit)
0x000000004227 (Hit)
0x000000004228 (Hit)
0x000000004229 (Hit)
0x00000000422a (Hit)
0x00000000422b (Hit)
0x00000000422c (Hit)
0x00000000422d (Hit)
0x00000000422e (Hit)
0x00000000422f (Hit)
0x000000004230 (Hit)
0x000000004231 (Hit)
0x000000004232 (Hit)
0x000000004233 (Hit)
0x000000004234 (Hit)
0x000000004235 (Hit)
0x000000004236 (Hit)
0x000000004237 (Hit)
0x000000004238 (Hit)
0x000000004239 (Hit)
0x00000000423a (Hit)
0x00000000423b (Hit)
0x00000000423c (Hit)
0x00000000423d (Hit)
0x00000000423e (Hit)
0x00000000423f (Hit)
This is the output using memGen5, line size = 128, and number of ways = 4
Number of hits = 999488
Number of misses = 512
Hit ratio = 99.9488
Miss ratio = 0.0512
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

## Experiment #1, memGen6:

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x0000042e0 (Hit)
0x000004300 (Hit)
0x000004320 (Hit)
0x000004340 (Hit)
0x000004360 (Hit)
0x000004380 (Hit)
0x0000043a0 (Hit)
0x0000043c0 (Hit)
0x0000043e0 (Hit)
0x000004400 (Hit)
0x000004420 (Hit)
0x000004440 (Hit)
0x000004460 (Hit)
0x000004480 (Hit)
0x0000044a0 (Hit)
0x0000044c0 (Hit)
0x0000044e0 (Hit)
0x000004500 (Hit)
0x000004520 (Hit)
0x000004540 (Hit)
0x000004560 (Hit)
0x000004580 (Hit)
0x0000045a0 (Hit)
0x0000045c0 (Hit)
0x0000045e0 (Hit)
0x000004600 (Hit)
0x000004620 (Hit)
0x000004640 (Hit)
0x000004660 (Hit)
0x000004680 (Hit)
0x0000046a0 (Hit)
0x0000046c0 (Hit)
0x0000046e0 (Hit)
0x000004700 (Hit)
0x000004720 (Hit)
0x000004740 (Hit)
0x000004760 (Hit)
0x000004780 (Hit)
0x0000047a0 (Hit)
0x0000047c0 (Hit)
0x0000047e0 (Hit)
0x000004800 (Hit)
This is the output using memGen6, line size = 16, and number of ways = 4
Number of hits = 185920
Number of misses = 814080
Hit ratio = 18.592
Miss ratio = 81.408
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x0000042e0 (Hit)
0x000004380 (Hit)
0x0000043a0 (Hit)
0x0000043c0 (Hit)
0x0000043e0 (Hit)
0x000004400 (Hit)
0x000004420 (Hit)
0x000004440 (Hit)
0x000004460 (Hit)
0x000004480 (Hit)
0x0000044a0 (Hit)
0x0000044c0 (Hit)
0x000004500 (Hit)
0x000004520 (Hit)
0x000004540 (Hit)
0x000004560 (Hit)
0x000004580 (Hit)
0x0000045a0 (Hit)
0x0000045c0 (Hit)
0x0000045e0 (Hit)
0x000004600 (Hit)
0x000004620 (Hit)
0x000004640 (Hit)
0x000004660 (Hit)
0x000004680 (Hit)
0x0000046a0 (Hit)
0x0000046c0 (Hit)
0x0000046e0 (Hit)
0x000004700 (Hit)
0x000004720 (Hit)
0x000004740 (Hit)
0x000004760 (Hit)
0x000004780 (Hit)
0x0000047a0 (Hit)
0x0000047c0 (Hit)
0x0000047e0 (Hit)
0x000004800 (Hit)
This is the output using memGen6, line size = 32, and number of ways = 4
Number of hits = 185920
Number of misses = 814080
Hit ratio = 18.592
Miss ratio = 81.408
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

Please start a debug session to evaluate expressions.

```

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x0000042e0 (Hit)
0x000004300 (Hit)
0x000004320 (Hit)
0x000004340 (Hit)
0x000004360 (Hit)
0x000004380 (Hit)
0x0000043a0 (Hit)
0x0000043c0 (Hit)
0x0000043e0 (Hit)
0x000004400 (Hit)
0x000004420 (Hit)
0x000004440 (Hit)
0x000004460 (Hit)
0x000004480 (Hit)
0x0000044a0 (Hit)
0x0000044c0 (Hit)
0x0000044e0 (Hit)
0x000004500 (Hit)
0x000004520 (Hit)
0x000004540 (Hit)
0x000004560 (Hit)
0x000004580 (Hit)
0x0000045a0 (Hit)
0x0000045c0 (Hit)
0x0000045e0 (Hit)
0x000004600 (Hit)
0x000004620 (Hit)
0x000004640 (Hit)
0x000004660 (Hit)
0x000004680 (Hit)
0x0000046a0 (Hit)
0x0000046c0 (Hit)
0x0000046e0 (Hit)
0x000004700 (Hit)
0x000004720 (Hit)
0x000004740 (Hit)
0x000004760 (Hit)
0x000004780 (Hit)
0x0000047a0 (Hit)
0x0000047c0 (Hit)
0x0000047e0 (Hit)
0x000004800 (Hit)
This is the output using memGen6, line size = 64, and number of ways = 4
Number of hits = 592960
Number of misses = 407040
Hit ratio = 59.296
Miss ratio = 40.704
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x0000042e0 (Hit)
0x000004300 (Hit)
0x000004320 (Hit)
0x000004340 (Hit)
0x000004360 (Hit)
0x000004380 (Hit)
0x0000043a0 (Hit)
0x0000043c0 (Hit)
0x0000043e0 (Hit)
0x000004400 (Hit)
0x000004420 (Hit)
0x000004440 (Hit)
0x000004460 (Hit)
0x000004480 (Hit)
0x0000044a0 (Hit)
0x0000044c0 (Hit)
0x000004500 (Hit)
0x000004520 (Hit)
0x000004540 (Hit)
0x000004560 (Hit)
0x000004580 (Hit)
0x0000045a0 (Hit)
0x0000045c0 (Hit)
0x0000045e0 (Hit)
0x000004600 (Hit)
0x000004620 (Hit)
0x000004640 (Hit)
0x000004660 (Hit)
0x000004680 (Hit)
0x0000046a0 (Hit)
0x0000046c0 (Hit)
0x0000046e0 (Hit)
0x000004700 (Hit)
0x000004720 (Hit)
0x000004740 (Hit)
0x000004760 (Hit)
0x000004780 (Hit)
0x0000047a0 (Hit)
0x0000047c0 (Hit)
0x0000047e0 (Hit)
0x000004800 (Hit)
This is the output using memGen6, line size = 128, and number of ways = 4
Number of hits = 796480
Number of misses = 203520
Hit ratio = 79.648
Miss ratio = 20.352
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

**Experiment #2 memgen1():**

```
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 16, and number of ways = 1
Number of hits = 937500
Number of misses = 62500
Hit ratio = 93.75
Miss ratio = 6.25
Program ended with exit code: 0
```

```
0x000f423c (Hit)
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 16, and number of ways = 2
Number of hits = 937500
Number of misses = 62500
Hit ratio = 93.75
Miss ratio = 6.25
Program ended with exit code: 0
```

```
0x000f423c (Hit)
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 16, and number of ways = 4
Number of hits = 937500
Number of misses = 62500
Hit ratio = 93.75
Miss ratio = 6.25
Program ended with exit code: 0
```

```
0x000f423d (Hit)
0x000f423e (Hit)
0x000f423f (Hit)
This is the output using memGen1, line size = 16, and number of ways = 8
Number of hits = 937500
Number of misses = 62500
Hit ratio = 93.75
Miss ratio = 6.25
Program ended with exit code: 0
```

## Experiment #2, memgen2():

```
0x0000032c1 (Hit)
This is the output using memGen2, line size = 16, and number of ways = 1
Number of hits = 998464
Number of misses = 1536
Hit ratio = 99.8464
Miss ratio = 0.1536
Program ended with exit code: 0

0x0000030a4 (Hit)
0x00000a16 (Hit)
0x000011a4 (Hit)
0x000032c1 (Hit)
This is the output using memGen2, line size = 16, and number of ways = 2
Number of hits = 998464
Number of misses = 1536
Hit ratio = 99.8464
Miss ratio = 0.1536
Program ended with exit code: 0

0x0000030a4 (Hit)
0x00000a16 (Hit)
0x000011a4 (Hit)
0x000032c1 (Hit)
This is the output using memGen2, line size = 16, and number of ways = 4
Number of hits = 998464
Number of misses = 1536
Hit ratio = 99.8464
Miss ratio = 0.1536
Program ended with exit code: 0

0x00000a16 (Hit)
0x000011a4 (Hit)
0x000032c1 (Hit)
This is the output using memGen2, line size = 16, and number of ways = 8
Number of hits = 998464
Number of misses = 1536
Hit ratio = 99.8464
Miss ratio = 0.1536
Program ended with exit code: 0
```

**Experiment #2, memgen3():**

```
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 16, and number of ways = 1
Number of hits = 1021
Number of misses = 998979
Hit ratio = 0.1021
Miss ratio = 99.8979
Program ended with exit code: 0

0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 16, and number of ways = 2
Number of hits = 1007
Number of misses = 998993
Hit ratio = 0.1007
Miss ratio = 99.8993
Program ended with exit code: 0

0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 16, and number of ways = 4
Number of hits = 968
Number of misses = 999032
Hit ratio = 0.0968
Miss ratio = 99.9032
Program ended with exit code: 0

0x01f8ca16 (Miss)
0x026431a4 (Miss)
0x025792c1 (Miss)
This is the output using memGen3, line size = 16, and number of ways = 8
Number of hits = 1000
Number of misses = 999000
Hit ratio = 0.1
Miss ratio = 99.9
Program ended with exit code: 0
```

## Experiment #2, memGen4:

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 16, and number of ways = 1
Number of hits = 999744
Number of misses = 256
Hit ratio = 99.9744
Miss ratio = 0.0256
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 16, and number of ways = 2
Number of hits = 999744
Number of misses = 256
Hit ratio = 99.9744
Miss ratio = 0.0256
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 16, and number of ways = 4
Number of hits = 999744
Number of misses = 256
Hit ratio = 99.9744
Miss ratio = 0.0256
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER
0x000000210 (Hit)
0x000000217 (Hit)
0x000000218 (Hit)
0x000000219 (Hit)
0x00000021a (Hit)
0x00000021b (Hit)
0x00000021c (Hit)
0x00000021d (Hit)
0x00000021e (Hit)
0x00000021f (Hit)
0x000000220 (Hit)
0x000000221 (Hit)
0x000000222 (Hit)
0x000000223 (Hit)
0x000000224 (Hit)
0x000000225 (Hit)
0x000000226 (Hit)
0x000000227 (Hit)
0x000000228 (Hit)
0x000000229 (Hit)
0x00000022a (Hit)
0x00000022b (Hit)
0x00000022c (Hit)
0x00000022d (Hit)
0x00000022e (Hit)
0x00000022f (Hit)
0x000000230 (Hit)
0x000000231 (Hit)
0x000000232 (Hit)
0x000000233 (Hit)
0x000000234 (Hit)
0x000000235 (Hit)
0x000000236 (Hit)
0x000000237 (Hit)
0x000000238 (Hit)
0x000000239 (Hit)
0x00000023a (Hit)
0x00000023b (Hit)
0x00000023c (Hit)
0x00000023d (Hit)
0x00000023e (Hit)
0x00000023f (Hit)
This is the output using memGen4, line size = 16, and number of ways = 8
Number of hits = 999744
Number of misses = 256
Hit ratio = 99.9744
Miss ratio = 0.0256
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).

```

## Experiment #2, memGen5:

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000004210 (Hit)
0x000004217 (Hit)
0x000004218 (Hit)
0x000004219 (Hit)
0x00000421a (Hit)
0x00000421b (Hit)
0x00000421c (Hit)
0x00000421d (Hit)
0x00000421e (Hit)
0x00000421f (Hit)
0x000004220 (Hit)
0x000004221 (Hit)
0x000004222 (Hit)
0x000004223 (Hit)
0x000004224 (Hit)
0x000004225 (Hit)
0x000004226 (Hit)
0x000004227 (Hit)
0x000004228 (Hit)
0x000004229 (Hit)
0x00000422a (Hit)
0x00000422b (Hit)
0x00000422c (Hit)
0x00000422d (Hit)
0x00000422e (Hit)
0x00000422f (Hit)
0x000004230 (Hit)
0x000004231 (Hit)
0x000004232 (Hit)
0x000004233 (Hit)
0x000004234 (Hit)
0x000004235 (Hit)
0x000004236 (Hit)
0x000004237 (Hit)
0x000004238 (Hit)
0x000004239 (Hit)
0x00000423a (Hit)
0x00000423b (Hit)
0x00000423c (Hit)
0x00000423d (Hit)
0x00000423e (Hit)
0x00000423f (Hit)
This is the output using memGen5, line size = 16, and number of ways = 1
Number of hits = 995904
Number of misses = 4096
Hit ratio = 99.5904
Miss ratio = 0.4096
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000004210 (Hit)
0x000004217 (Hit)
0x000004218 (Hit)
0x000004219 (Hit)
0x00000421a (Hit)
0x00000421b (Hit)
0x00000421c (Hit)
0x00000421d (Hit)
0x00000421e (Hit)
0x00000421f (Hit)
0x000004220 (Hit)
0x000004221 (Hit)
0x000004222 (Hit)
0x000004223 (Hit)
0x000004224 (Hit)
0x000004225 (Hit)
0x000004226 (Hit)
0x000004227 (Hit)
0x000004228 (Hit)
0x000004229 (Hit)
0x00000422a (Hit)
0x00000422b (Hit)
0x00000422c (Hit)
0x00000422d (Hit)
0x00000422e (Hit)
0x00000422f (Hit)
0x000004230 (Hit)
0x000004231 (Hit)
0x000004232 (Hit)
0x000004233 (Hit)
0x000004234 (Hit)
0x000004235 (Hit)
0x000004236 (Hit)
0x000004237 (Hit)
0x000004238 (Hit)
0x000004239 (Hit)
0x00000423a (Hit)
0x00000423b (Hit)
0x00000423c (Hit)
0x00000423d (Hit)
0x00000423e (Hit)
0x00000423f (Hit)
This is the output using memGen5, line size = 16, and number of ways = 2
Number of hits = 995904
Number of misses = 4096
Hit ratio = 99.5904
Miss ratio = 0.4096
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000004210 (Hit)
0x000004217 (Hit)
0x000004218 (Hit)
0x000004219 (Hit)
0x00000421a (Hit)
0x00000421b (Hit)
0x00000421c (Hit)
0x00000421d (Hit)
0x00000421e (Hit)
0x00000421f (Hit)
0x000004220 (Hit)
0x000004221 (Hit)
0x000004222 (Hit)
0x000004223 (Hit)
0x000004224 (Hit)
0x000004225 (Hit)
0x000004226 (Hit)
0x000004227 (Hit)
0x000004228 (Hit)
0x000004229 (Hit)
0x00000422a (Hit)
0x00000422b (Hit)
0x00000422c (Hit)
0x00000422d (Hit)
0x00000422e (Hit)
0x00000422f (Hit)
0x000004230 (Hit)
0x000004231 (Hit)
0x000004232 (Hit)
0x000004233 (Hit)
0x000004234 (Hit)
0x000004235 (Hit)
0x000004236 (Hit)
0x000004237 (Hit)
0x000004238 (Hit)
0x000004239 (Hit)
0x00000423a (Hit)
0x00000423b (Hit)
0x00000423c (Hit)
0x00000423d (Hit)
0x00000423e (Hit)
0x00000423f (Hit)
This is the output using memGen5, line size = 16, and number of ways = 4
Number of hits = 995904
Number of misses = 4096
Hit ratio = 99.5904
Miss ratio = 0.4096
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x000004210 (Hit)
0x000004217 (Hit)
0x000004218 (Hit)
0x000004219 (Hit)
0x00000421a (Hit)
0x00000421b (Hit)
0x00000421c (Hit)
0x00000421d (Hit)
0x00000421e (Hit)
0x00000421f (Hit)
0x000004220 (Hit)
0x000004221 (Hit)
0x000004222 (Hit)
0x000004223 (Hit)
0x000004224 (Hit)
0x000004225 (Hit)
0x000004226 (Hit)
0x000004227 (Hit)
0x000004228 (Hit)
0x000004229 (Hit)
0x00000422a (Hit)
0x00000422b (Hit)
0x00000422c (Hit)
0x00000422d (Hit)
0x00000422e (Hit)
0x00000422f (Hit)
0x000004230 (Hit)
0x000004231 (Hit)
0x000004232 (Hit)
0x000004233 (Hit)
0x000004234 (Hit)
0x000004235 (Hit)
0x000004236 (Hit)
0x000004237 (Hit)
0x000004238 (Hit)
0x000004239 (Hit)
0x00000423a (Hit)
0x00000423b (Hit)
0x00000423c (Hit)
0x00000423d (Hit)
0x00000423e (Hit)
0x00000423f (Hit)
This is the output using memGen5, line size = 16, and number of ways = 8
Number of hits = 995904
Number of misses = 4096
Hit ratio = 99.5904
Miss ratio = 0.4096
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

## Experiment #2, memGen6:

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x0000012e0 (Miss)
0x000004300 (Miss)
0x000004320 (Miss)
0x000004340 (Miss)
0x000004360 (Miss)
0x000004380 (Miss)
0x0000043a0 (Miss)
0x0000043c0 (Miss)
0x0000043e0 (Miss)
0x000004400 (Miss)
0x000004420 (Miss)
0x000004440 (Miss)
0x000004460 (Miss)
0x000004480 (Miss)
0x0000044a0 (Miss)
0x0000044c0 (Miss)
0x0000044e0 (Miss)
0x000004500 (Miss)
0x000004520 (Miss)
0x000004540 (Miss)
0x000004560 (Miss)
0x000004580 (Miss)
0x0000045a0 (Miss)
0x0000045c0 (Miss)
0x0000045e0 (Miss)
0x000004600 (Miss)
0x000004620 (Miss)
0x000004640 (Miss)
0x000004660 (Miss)
0x000004680 (Miss)
0x0000046a0 (Miss)
0x0000046c0 (Miss)
0x0000046e0 (Miss)
0x000004700 (Miss)
0x000004720 (Miss)
0x000004740 (Miss)
0x000004760 (Miss)
0x000004780 (Miss)
0x0000047a0 (Miss)
0x0000047c0 (Miss)
0x0000047e0 (Miss)
0x000004800 (Miss)
This is the output using memGen6, line size = 16, and number of ways = 1
Number of hits = 0
Number of misses = 1000000
Hit ratio = 0
Miss ratio = 100
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x0000012e0 (Miss)
0x000004300 (Miss)
0x000004320 (Miss)
0x000004340 (Miss)
0x000004360 (Miss)
0x000004380 (Miss)
0x0000043a0 (Miss)
0x0000043c0 (Miss)
0x0000043e0 (Miss)
0x000004400 (Miss)
0x000004420 (Miss)
0x000004440 (Miss)
0x000004460 (Miss)
0x000004480 (Miss)
0x0000044a0 (Miss)
0x0000044c0 (Miss)
0x0000044e0 (Miss)
0x000004500 (Miss)
0x000004520 (Miss)
0x000004540 (Miss)
0x000004560 (Miss)
0x000004580 (Miss)
0x0000045a0 (Miss)
0x0000045c0 (Miss)
0x0000045e0 (Miss)
0x000004600 (Miss)
0x000004620 (Miss)
0x000004640 (Miss)
0x000004660 (Miss)
0x000004680 (Miss)
0x0000046a0 (Miss)
0x0000046c0 (Miss)
0x0000046e0 (Miss)
0x000004700 (Miss)
0x000004720 (Miss)
0x000004740 (Miss)
0x000004760 (Miss)
0x000004780 (Miss)
0x0000047a0 (Miss)
0x0000047c0 (Miss)
0x0000047e0 (Miss)
0x000004800 (Miss)
This is the output using memGen6, line size = 16, and number of ways = 2
Number of hits = 123904
Number of misses = 876096
Hit ratio = 12.3904
Miss ratio = 87.6096
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x0000012e0 (Hit)
0x000004300 (Hit)
0x000004320 (Hit)
0x000004340 (Hit)
0x000004360 (Hit)
0x000004380 (Hit)
0x0000043a0 (Hit)
0x0000043c0 (Hit)
0x0000043e0 (Hit)
0x000004400 (Hit)
0x000004420 (Hit)
0x000004440 (Hit)
0x000004460 (Hit)
0x000004480 (Hit)
0x0000044a0 (Hit)
0x0000044c0 (Hit)
0x0000044e0 (Hit)
0x000004500 (Hit)
0x000004520 (Hit)
0x000004540 (Hit)
0x000004560 (Hit)
0x000004580 (Hit)
0x0000045a0 (Hit)
0x0000045c0 (Hit)
0x0000045e0 (Hit)
0x000004600 (Hit)
0x000004620 (Hit)
0x000004640 (Hit)
0x000004660 (Hit)
0x000004680 (Hit)
0x0000046a0 (Hit)
0x0000046c0 (Hit)
0x0000046e0 (Hit)
0x000004700 (Hit)
0x000004720 (Hit)
0x000004740 (Hit)
0x000004760 (Hit)
0x000004780 (Hit)
0x0000047a0 (Hit)
0x0000047c0 (Hit)
0x0000047e0 (Hit)
0x000004800 (Hit)
This is the output using memGen6, line size = 16, and number of ways = 4
Number of hits = 185920
Number of misses = 814080
Hit ratio = 18.592
Miss ratio = 81.408
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```

PROBLEMS 3 OUTPUT DEBUG CONSOLE TERMINAL JUPYTER

```
0x0000012e0 (Hit)
0x000004300 (Hit)
0x000004320 (Hit)
0x000004340 (Hit)
0x000004360 (Hit)
0x000004380 (Hit)
0x0000043a0 (Hit)
0x0000043c0 (Hit)
0x0000043e0 (Hit)
0x000004400 (Hit)
0x000004420 (Hit)
0x000004440 (Hit)
0x000004460 (Hit)
0x000004480 (Hit)
0x0000044a0 (Hit)
0x0000044c0 (Hit)
0x0000044e0 (Hit)
0x000004500 (Hit)
0x000004520 (Hit)
0x000004540 (Hit)
0x000004560 (Hit)
0x000004580 (Hit)
0x0000045a0 (Hit)
0x0000045c0 (Hit)
0x0000045e0 (Hit)
0x000004600 (Hit)
0x000004620 (Hit)
0x000004640 (Hit)
0x000004660 (Hit)
0x000004680 (Hit)
0x0000046a0 (Hit)
0x0000046c0 (Hit)
0x0000046e0 (Hit)
0x000004700 (Hit)
0x000004720 (Hit)
0x000004740 (Hit)
0x000004760 (Hit)
0x000004780 (Hit)
0x0000047a0 (Hit)
0x0000047c0 (Hit)
0x0000047e0 (Hit)
0x000004800 (Hit)
This is the output using memGen6, line size = 16, and number of ways = 8
Number of hits = 217152
Number of misses = 782848
Hit ratio = 21.7152
Miss ratio = 78.2848
The program '/Users/salmaaly/Desktop/assembly_proj2/cache' has exited with code 0 (0x00000000).
```