Computer Architecture
DAT105
Exercise Session 4

M. WAQAR AZHAR
waqarm@chalmers.se

Chalmers University of Technology, Sweden

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Agenda

- Problem 4.3
- Problem 4.5
- Problem 4.8

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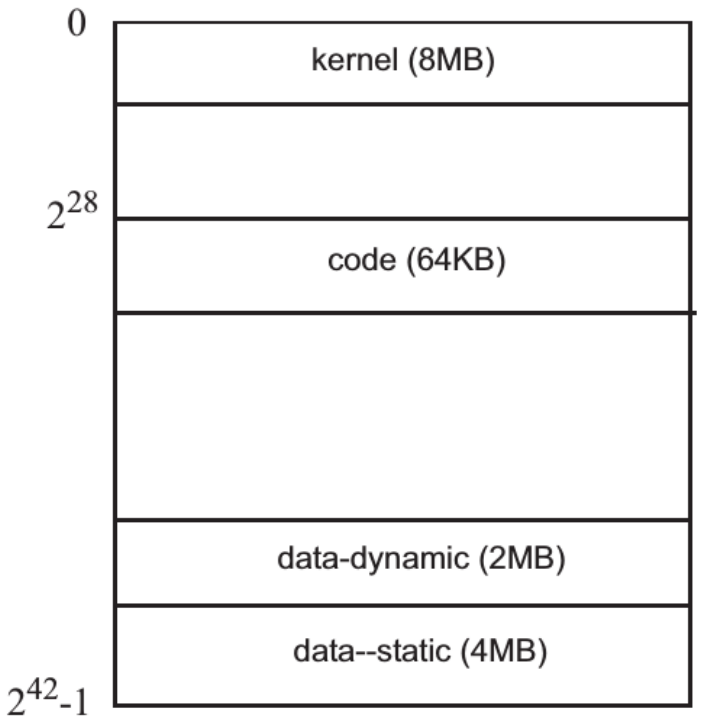
- Problem 4.3
- Problem 4.5
- Problem 4.8

Problem 4.3

This problem is about the structure of page tables to support large virtual address spaces. Assume a 42-bit virtual address space per process in a 64-bit machine and 512 MByte of main memory. The page size is 4KBytes. Page table entries are 4 byte in every table. Various hierarchical page table organizations are envisioned: 1, 2, and 3 levels. The virtual space to map is populated as shown in Figure 4.21. Kernel space addresses are not translated because physical addresses are identical to virtual addresses. However virtual addresses in all other segments must be translated.



Problem 4.3 (Part-1)

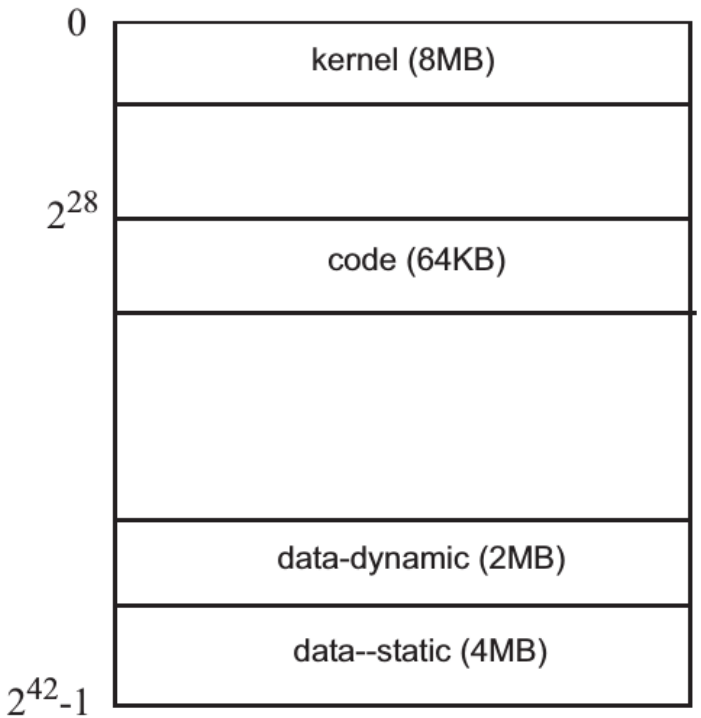
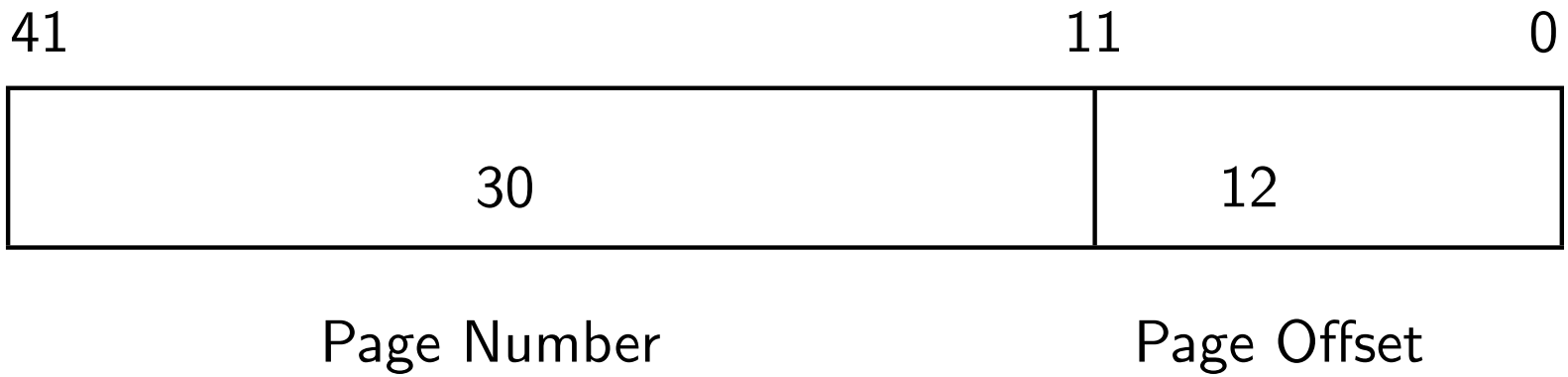


Figure 4.21. Virtual address space mapping

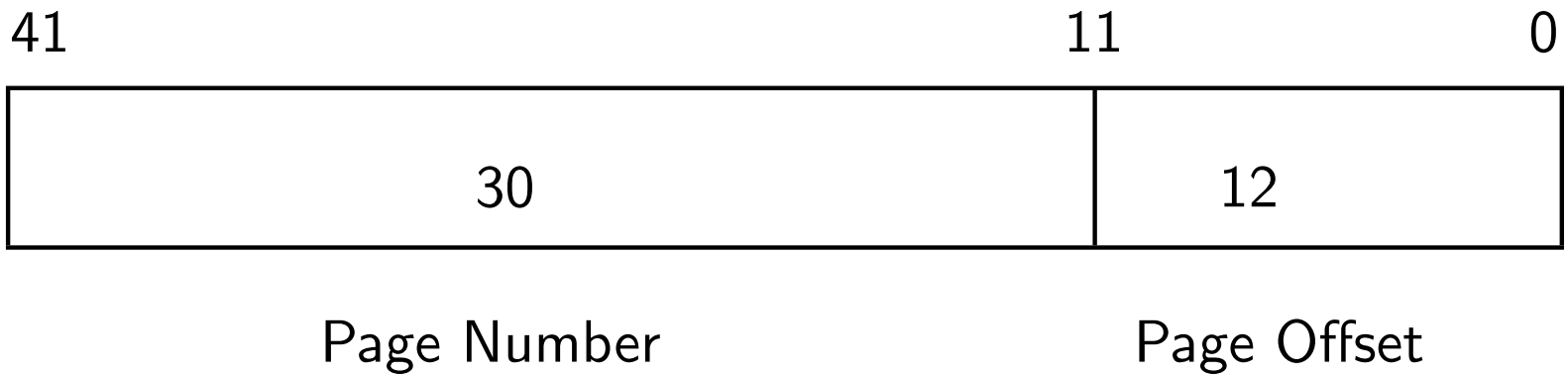
Q1 : What would be the size of a single-level page table?

Problem 4.3 (Part-1)



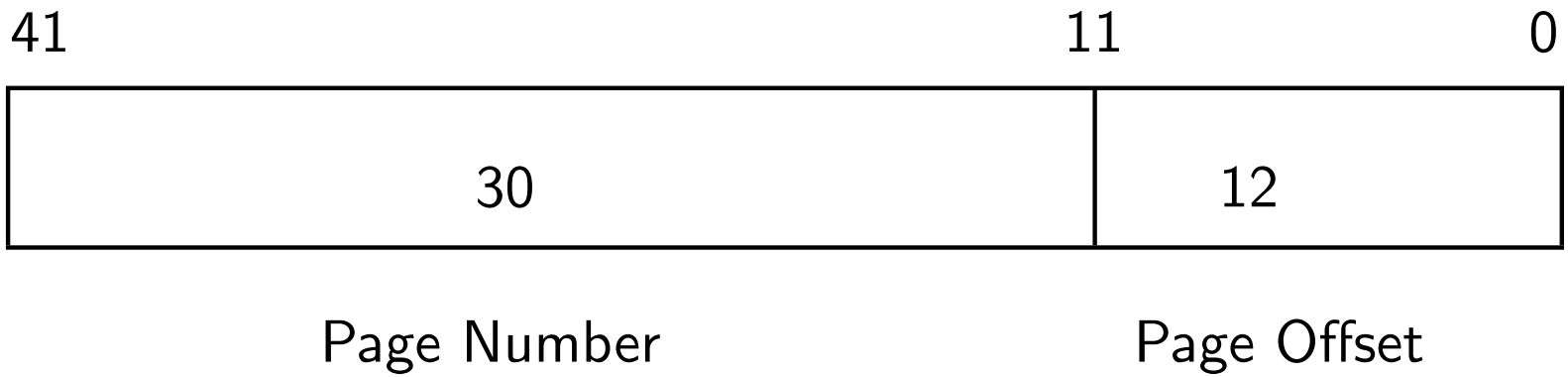
Virtual Address space has 42 bits.

Problem 4.3 (Part-1)



Virtual Address space has 42 bits.
Page size = 4 KBytes = 2^{12}

Problem 4.3 (Part-1)



Virtual Address space has 42 bits.
Page size = 4 KBytes = 2^{12}
No of pages = $2^{42-12} = 2^{30}$

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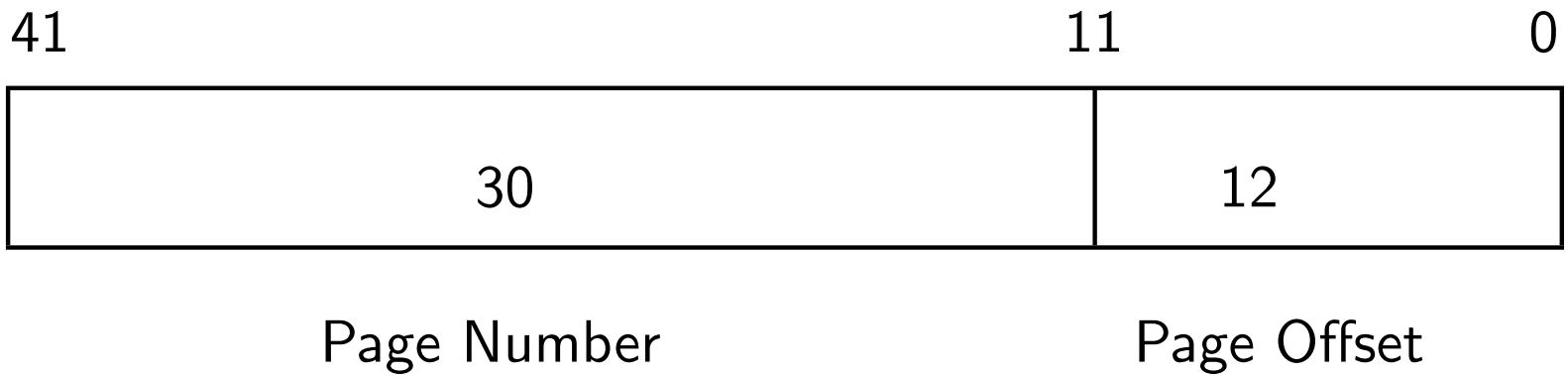
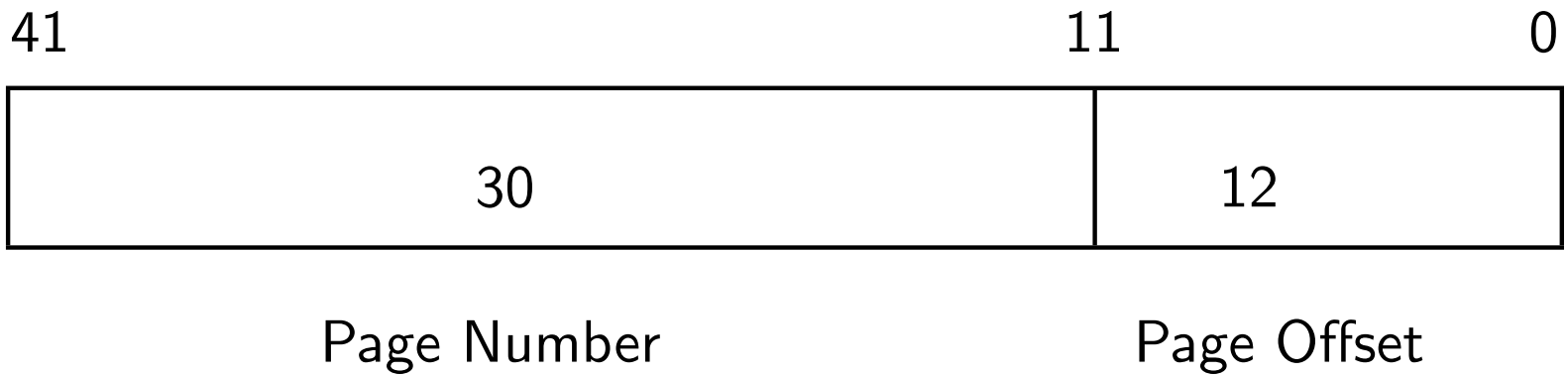


Virtual Address space has 42 bits.
Page size = 4 KBytes = 2^{12}
No of pages = $2^{42-12} = 2^{30}$
For this we need = $\frac{30}{8} = 3.75 = 4$ Bytes

Problem 4.3 (Part-1)

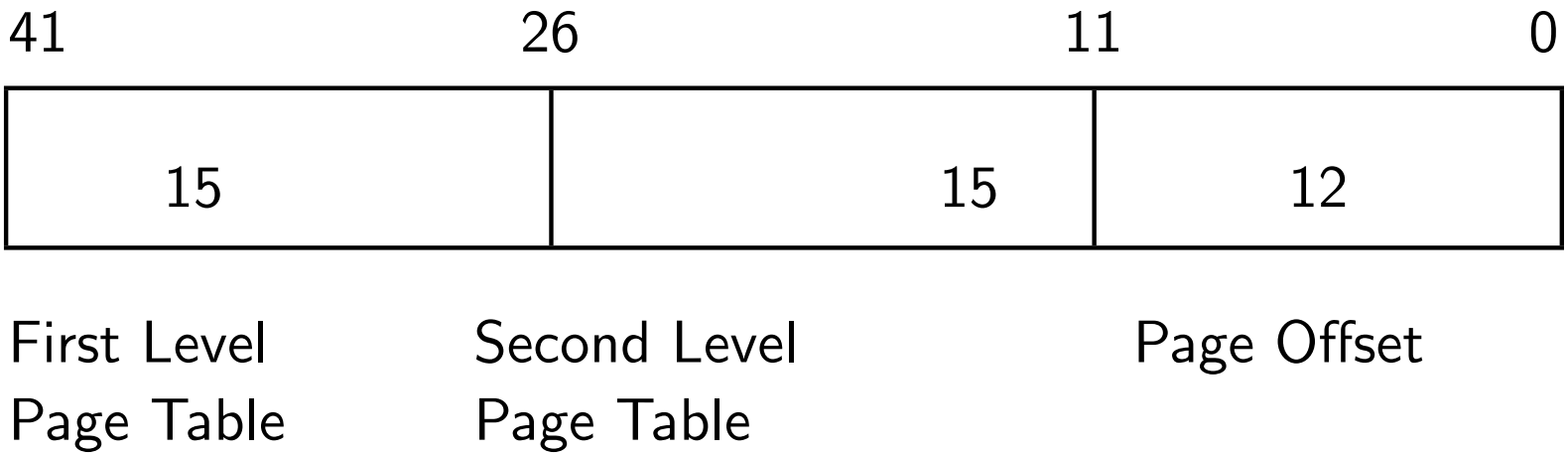


Virtual Address space has 42 bits.
Page size = 4 KBytes = 2^{12}
No of pages = $2^{42-12} = 2^{30}$
For this we need $= \frac{30}{8} = 3.75 = 4$ Bytes
Page Table size $4 * 2^{30} = 4GB$

Problem 4.3 (Part-2)

Q2: Assume now a 2-level page table. We split the 30 bits of virtual page number into two fields of 15-bits each? How many page tables would we have? What would be their total size?

Problem 4.3 (Part-2)



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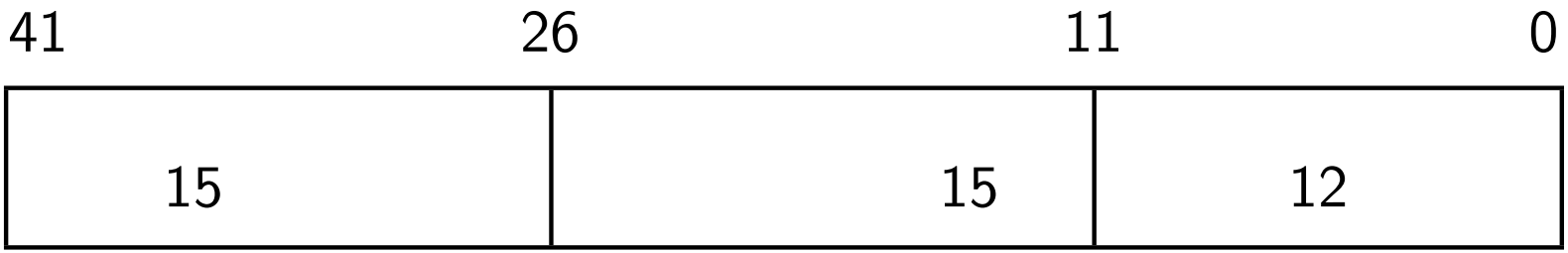


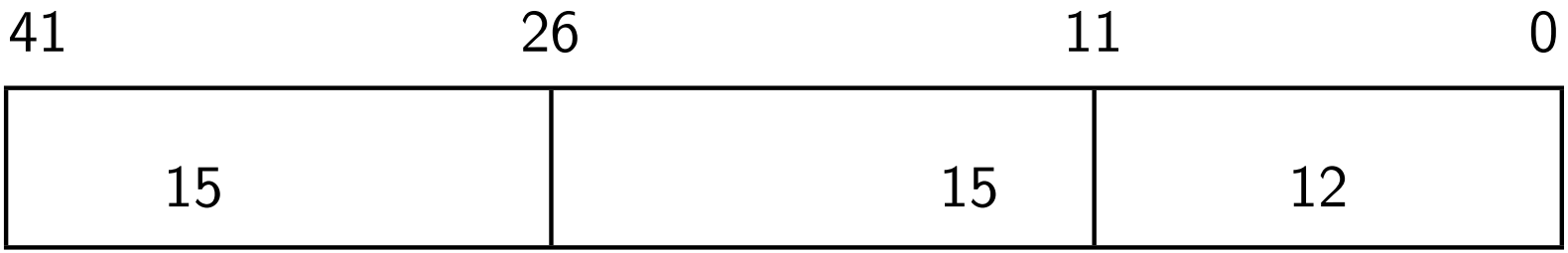
First Level Page Table

Second Level Page Table

Page Offset

No of entries in first level table$= 2^{15} = 2^5 * 2^{10} = 32K$

Problem 4.3 (Part-2)



No of entries in first level table$= 2^{15} = 2^5 * 2^{10} = 32K$
Size of Entry$= 4$ bytes.

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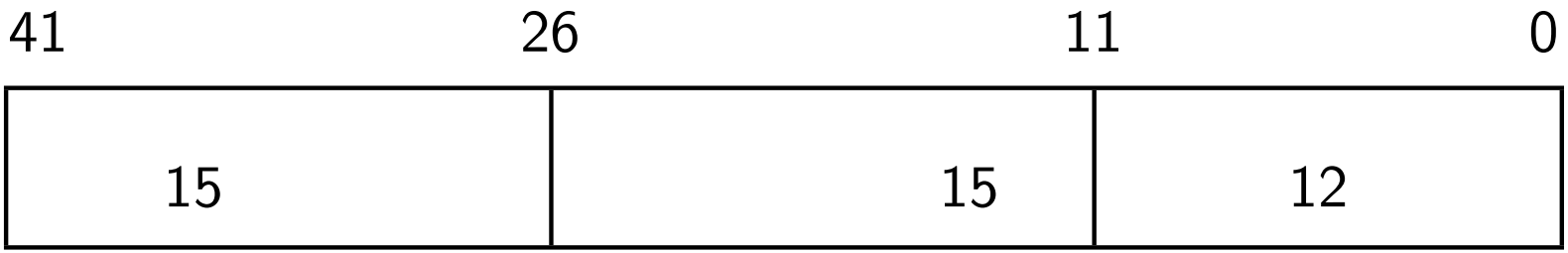

No of entries in first level table$= 2^{15} = 2^5 * 2^{10} = 32K$
Size of Entry$= 4$ bytes. Total size $= 32K * 4 = 128KB$

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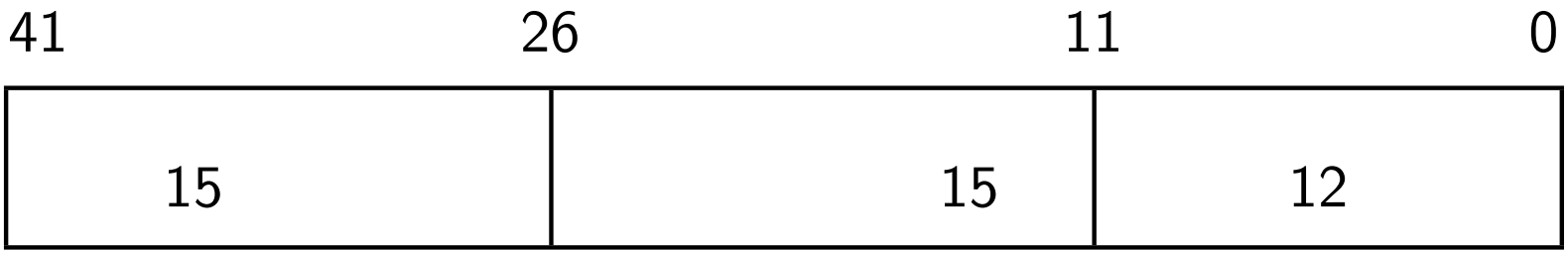

No of entries in first level table$= 2^{15} = 2^5 * 2^{10} = 32K$
Size of Entry$= 4$ bytes. Total size $= 32K * 4 = 128KB$
Each entry of the first-level page table covers
$2^{15+12} = 2^{27} = 128MB$ of virtual memory.

Problem 4.3 (Part-2)

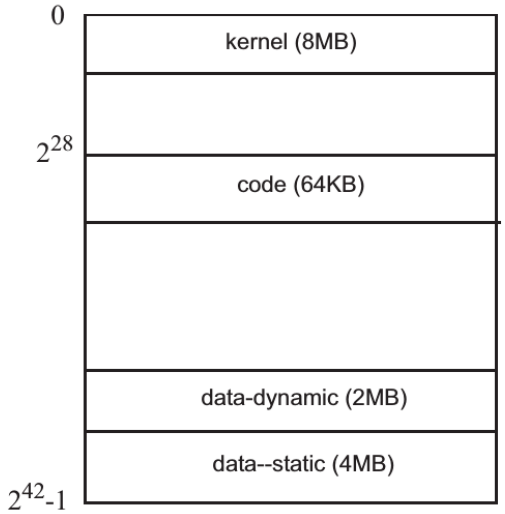

Figure 4.21. Virtual address space mapping

The code segment lies in the virtual memory area covered by the second entry of the first-level page table.

Problem 4.3 (Part-2)

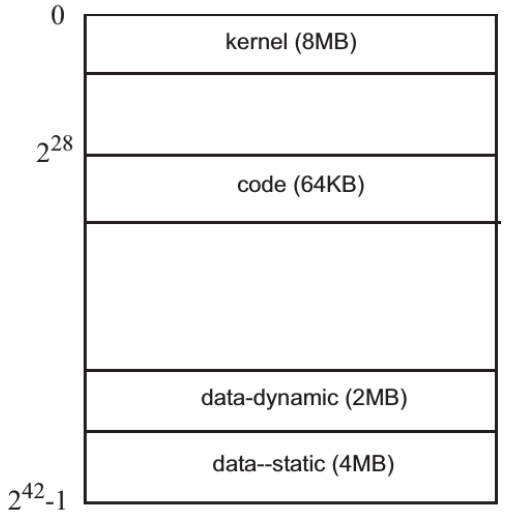

Figure 4.21. Virtual address space mapping

The code segment lies in the virtual memory area covered by the second entry of the first-level page table.
The two data segments lie in the virtual memory area covered by the last entry of the first-level page table.

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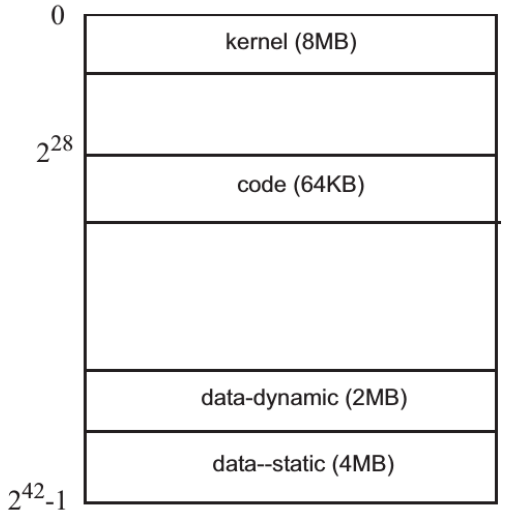

Figure 4.21. Virtual address space mapping

The code segment lies in the virtual memory area covered by the second entry of the first-level page table.
The two data segments lie in the virtual memory area covered by the last entry of the first-level page table.
Therefore we need a total of two second-level page tables which occupy 128KB each.

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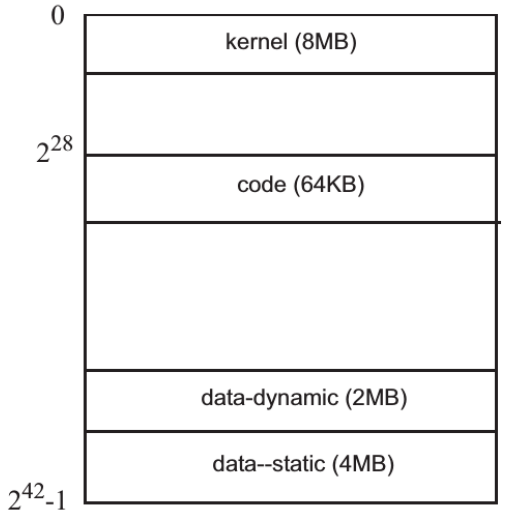

Figure 4.21. Virtual address space mapping

The code segment lies in the virtual memory area covered by the second entry of the first-level page table.
The two data segments lie in the virtual memory area covered by the last entry of the first-level page table.
Therefore we need a total of two second-level page tables which occupy 128KB each.
Thus the number of page tables is 3 and the total physical memory occupied by the page tables is $3x128KB = 384KB$.

Problem 4.3 (Part-3)

Q3: Repeat 2. for a 3-level page table splitting the 30 bits of virtual page number into 3 fields of 10 bits each.

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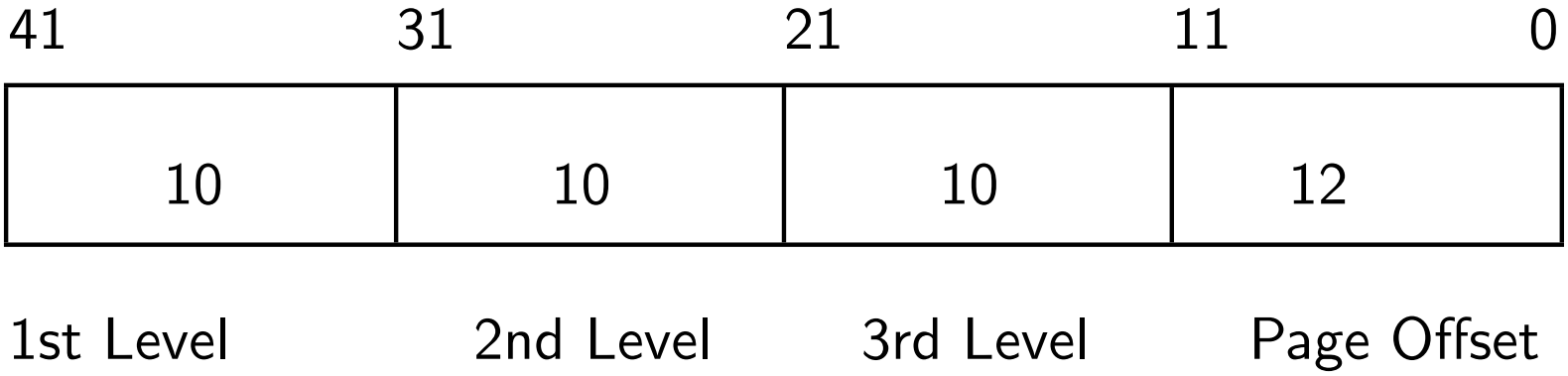

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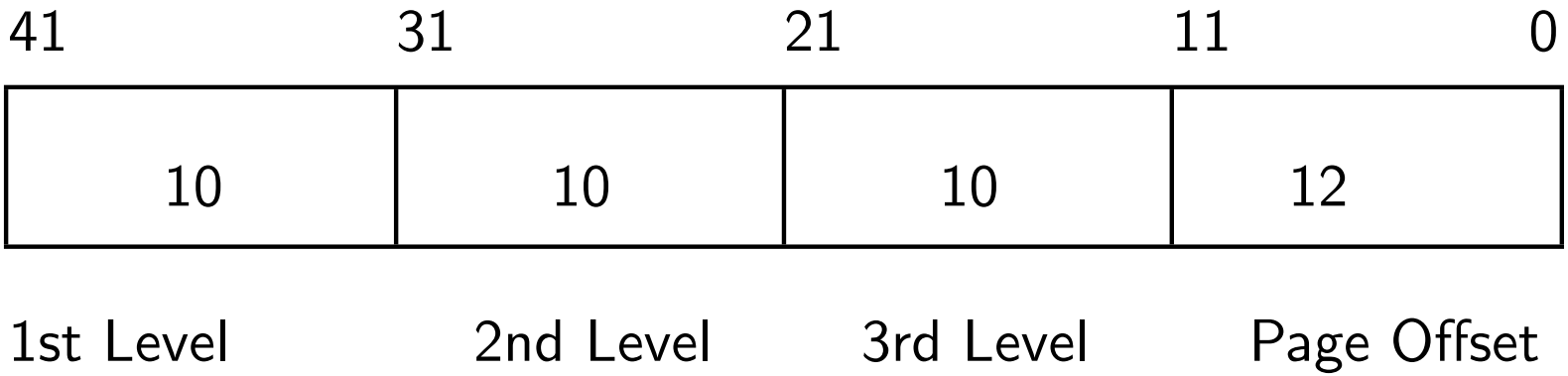

Level-1 table has $= 2^{10} = 1K$ entries.
Each Entry $= 4$ bytes.
Total size $= 4 * 1K = 4KB$.
A single entry of the first-level page table covers
$= 2^{10+10+12} = 2^{32} = 4GB$ of virtual space.

Problem 4.3 (Part-3)

Level-2 Page Table.
1 Table for code segment.
The two data segments lie in the virtual memory area covered by the last entry of the root page table. So we need another second level page table for the data (size 4KB).
Each entry of the second-level page tables covers
$2^{10+12} = 2^{22} = 4MB$ of virtual memory.

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Each entry of the second-level page tables covers
$2^{10+12} = 2^{22} = 4MB$ of virtual memory.
This is enough to cover the code segment (1-third-level table or 4KB). However the data segments requires two third-level page tables as they occupy 6MB of virtual memory.
The size of these two tables is 8KB. Thus the grand total is
$1 + 2 + 3 = 6$ tables.
Total physical memory occupation $= 6 * 4KB = 24KB$.

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Problem 4.5

In this problem, we explore cache mapping and cache replacement policies when memory references are cyclic or periodic. Such type of reference streams are common in accesses to instructions (loops) or in strided accesses to data.

First-level instruction caches are often direct-mapped, not only because direct-mapped caches are faster on a hit but also because they are better at handling loops than set-associative caches. Let's assume a cache with four lines (0,1,2 and 3) and a cyclic (periodic) block reference string with block addresses (0,1,2,3,4,5)10. This notation means that the reference string has a periodic pattern of accesses to block addresses 0,1,2,3,4, and 5 repeated 10 times. We classify misses into cold, capacity, and conflict misses. Capacity misses are counted in a FA cache with LRU replacement policy. In all cases the caches are empty at the beginning of the string.

Problem 4.5

Count the total number of misses in the following caches

- Direct-mapped
- FA with LRU replacement
- FA with FIFO replacement
- FA with LIFO (Last In First Out) replacement
- 2-way SA cache with LRU in each set

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty

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2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit

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	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	0	5	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	0	5	2	3	Miss
	1	0	1	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) Direct-mapped Cache

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
3	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	0	5	2	3	Miss
	1	0	1	2	3	Miss
	2	0	1	2	3	Hit
	3	0	1	2	3	Hit
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 4 = 42$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
	0	0	-	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
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	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
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$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
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2	0	4	5	0	3	Miss
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	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
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$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
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	5	4	5	2	3	Cold Miss
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	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
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Problem 4.5(a) F-A Cache with LRU

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	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
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4	0	4	5	0	3	Miss
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$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

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	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
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	3	0	1	2	3	Cold Miss
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	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LRU

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
	0	0	-	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
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$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
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	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
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Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
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$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss

Problem 4.5(a) F-A Cache with FIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	4	1	2	3	Cold Miss
	5	4	5	2	3	Cold Miss
2	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss
3	0	0	3	4	5	Miss
	1	0	1	4	5	Miss
	2	0	1	2	5	Miss
	3	0	1	2	3	Miss
	4	4	1	2	3	Miss
	5	4	5	2	3	Miss
4	0	4	5	0	3	Miss
	1	4	5	0	1	Miss
	2	2	5	0	1	Miss
	3	2	3	0	1	Miss
	4	2	3	4	1	Miss
	5	2	3	4	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment

Total Misses $= 6 + 9 * 3 = 33$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
	0	0	-	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit
	1	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss

Problem 4.5(a) F-A Cache with LIFO

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
3	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss
4	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	2	3	Miss
	4	0	1	2	4	Miss
	5	0	1	2	5	Miss

$$\text{Total Misses} = 6 + 9 * 3 = 33$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

		Set-1		Set-2		
Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment

Total Misses $= 6 + 9 * 6 = 60$

Problem 4.5(a) 2 way S-A Cache with LRU per set

		Set-1		Set-2		
Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
	0	0	-	-	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss

Total Misses $= 6 + 9 * 6 = 60$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss
	1	4	0	5	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss
	1	4	0	5	1	Miss
	2	2	0	5	1	Hit

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss
	1	4	0	5	1	Miss
	2	2	0	5	1	Hit
	3	2	0	3	1	Hit

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	-	1	-	Cold Miss
	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss
	1	4	0	5	1	Miss
	2	2	0	5	1	Hit
	3	2	0	3	1	Hit
	4	2	4	3	1	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

Problem 4.5(a) 2 way S-A Cache with LRU per set

Iteration	Reference	Set-1		Set-2		Comment
		Line-0	Line-1	Line-2	Line-3	
Cold	-	-	-	-	-	Cache is empty
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	2	0	2	1	-	Cold Miss
	3	0	2	1	3	Cold Miss
	4	4	2	1	3	Cold Miss
	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss
	1	4	0	5	1	Miss
	2	2	0	5	1	Hit
	3	2	0	3	1	Hit
	4	2	4	3	1	Miss
	5	2	4	3	5	Miss

$$\text{Total Misses} = 6 + 9 * 6 = 60$$

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	2	2	0	5	1	Hit
	3	2	0	3	1	Hit
	4	2	4	3	1	Miss
	5	2	4	3	5	Miss
3	0	0	4	3	5	Miss
	1	0	4	1	5	Miss
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Total Misses $= 6 + 9 * 6 = 60$

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	2	2	0	5	1	Hit
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	5	2	4	3	5	Miss
3	0	0	4	3	5	Miss
	1	0	4	1	5	Miss
	2	0	2	1	5	Miss
	3	0	2	1	3	Miss
	4	4	2	1	3	Miss
	5	4	2	5	3	Miss
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		Line-0	Line-1	Line-2	Line-3	
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	5	4	2	5	3	Cold Miss
2	0	4	0	5	3	Miss
	1	4	0	5	1	Miss
	2	2	0	5	1	Hit
	3	2	0	3	1	Hit
	4	2	4	3	1	Miss
	5	2	4	3	5	Miss
3	0	0	4	3	5	Miss
	1	0	4	1	5	Miss
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	3	0	2	1	3	Miss
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Total Misses $= 6 + 9 * 6 = 60$

Problem 4.5(b)COLD MISSES

The number of cold misses is independent of the cache organization and replacement policy. The number of cold misses is equal to the number of blocks in the trace

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Number pf cold misses = 6 misses

Problem 4.5(b)CAPACITY MISSES using FA-Opt

The number of capacity misses is also independent of the cache organization and replacement policy.

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Capacity misses = Number of misses in an FA LRU cache - Number of cold misses

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The number of capacity misses is also independent of the cache organization and replacement policy.

Capacity misses = Number of misses in an FA LRU cache - Number of cold misses

Number capacity misses = 60 - 6 = 54 misses

Problem 4.5(b)CONFLICT MISSES using FA-LRU

conflict misses = total number of misses - cold misses - capacity misses

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Direct-mapped: Number of conflict misses = 42 - (6 + 54) = -18 misses

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conflict misses = total number of misses - cold misses - capacity misses

Direct-mapped: Number of conflict misses = 42 - (6 + 54) = -18 misses

FA with LRU: Number of conflict misses = 60 - (6 + 54) = 0

FA with FIFO: Number of conflict misses = 60 - (6 + 54) = 0

Problem 4.5(b)CONFLICT MISSES using FA-LRU

conflict misses = total number of misses - cold misses - capacity misses

Direct-mapped: Number of conflict misses = 42 - (6 + 54) = -18 misses

FA with LRU: Number of conflict misses = 60 - (6 + 54) = 0

FA with FIFO: Number of conflict misses = 60 - (6 + 54) = 0

FA with LIFO: Number of conflict misses = 33 - (6 + 54) = -27 misses

Problem 4.5(b)CONFLICT MISSES using FA-LRU

conflict misses = total number of misses - cold misses - capacity misses

Direct-mapped: Number of conflict misses = 42 - (6 + 54) = -18 misses

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2-way SA with LRU for each set: Number of conflict misses = 60 - (6 + 54) = 0

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Problem 4.5(a) FA with OPT

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Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
	0	0	-	-	-	Cold Miss

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
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	2	0	1	2	-	Cold Miss

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Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
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	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
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1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
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	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
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	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit
4	0	0	3	4	5	Hit

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
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	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit
4	0	0	3	4	5	Hit
	1	1	3	4	5	Miss

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit
4	0	0	3	4	5	Hit
	1	1	3	4	5	Miss
	2	2	3	4	5	Miss

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit
4	0	0	3	4	5	Hit
	1	1	3	4	5	Miss
	2	2	3	4	5	Miss
	3	2	3	4	5	Hit

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit
4	0	0	3	4	5	Hit
	1	1	3	4	5	Miss
	2	2	3	4	5	Miss
	3	2	3	4	5	Hit
	4	2	3	4	5	Hit

Problem 4.5(a) FA with OPT

Iteration	Reference	Line-0	Line-1	Line-2	Line-3	Comment
Cold	-	-	-	-	-	Cache is empty
1	0	0	-	-	-	Cold Miss
	1	0	1	-	-	Cold Miss
	2	0	1	2	-	Cold Miss
	3	0	1	2	3	Cold Miss
	4	0	1	2	4	Cold Miss
	5	0	1	2	5	Cold Miss
2	0	0	1	2	5	Hit
	1	0	1	2	5	Hit
	2	0	1	2	5	Hit
	3	0	1	3	5	Miss
	4	0	1	4	5	Miss
	5	0	1	4	5	Hit
3	0	0	1	4	5	Hit
	1	0	1	4	5	Hit
	2	0	2	4	5	Miss
	3	0	3	4	5	Miss
	4	0	3	4	5	Hit
	5	0	3	4	5	Hit
4	0	0	3	4	5	Hit
	1	1	3	4	5	Miss
	2	2	3	4	5	Miss
	3	2	3	4	5	Hit
	4	2	3	4	5	Hit
	5	2	3	4	5	Hit

Problem 4.5(b)CONFLICT MISSES using FA-Opt

Total Misses FA-Opt= 27

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Direct-mapped: Number of conflict misses = 42 - 27 = 15 misses

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Problem 4.5(b)CONFLICT MISSES using FA-Opt

Total Misses FA-Opt= 27

Direct-mapped: Number of conflict misses = 42 - 27 = 15 misses

FA with LRU: Number of conflict misses = 60 - 27 = 33 misses

FA with FIFO: Number of conflict misses = 60 - 27 = 33 misses

Problem 4.5(b)CONFLICT MISSES using FA-Opt

Total Misses FA-Opt= 27

Direct-mapped: Number of conflict misses = 42 - 27 = 15 misses

FA with LRU: Number of conflict misses = 60 - 27 = 33 misses

FA with FIFO: Number of conflict misses = 60 - 27 = 33 misses

FA with LIFO: Number of conflict misses = 33 - 27 = 6 misses

Problem 4.5(b)CONFLICT MISSES using FA-Opt

Total Misses FA-Opt= 27

Direct-mapped: Number of conflict misses = 42 - 27 = 15 misses

FA with LRU: Number of conflict misses = 60 - 27 = 33 misses

FA with FIFO: Number of conflict misses = 60 - 27 = 33 misses

FA with LIFO: Number of conflict misses = 33 - 27 = 6 misses

2-way SA with LRU for each set: Number of conflict misses = 60 - 27 = 33 misses

Problem 4.5(b)CONFLICT MISSES using FA-Opt

Total Misses FA-Opt= 27

Direct-mapped: Number of conflict misses = 42 - 27 = 15 misses

FA with LRU: Number of conflict misses = 60 - 27 = 33 misses

FA with FIFO: Number of conflict misses = 60 - 27 = 33 misses

FA with LIFO: Number of conflict misses = 33 - 27 = 6 misses

2-way SA with LRU for each set: Number of conflict misses = 60 - 27 = 33 misses

Agenda

- Problem 4.3
- Problem 4.5
- Problem 4.8

Problem 4.8 (Problem Statement)

A simple program that accumulates values from a vector in memory is used in this problem

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,stridex4    // stridex4: stride multiplied by 4
ADD R1,R1,R4
BNE R3,R5,LOOP
```

The stride is the difference between the indexes of two consecutive vector elements. It is multiplied by 4 to find the address of consecutive vector components.

Problem 4.8

We examine the efficiency of this loop on the 5-stage pipeline with a blocking and a nonblocking data cache. The branch flushes the I-fetch and I-decode stages whenever it is taken.

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Throughout this problem the data cache is direct-mapped and is empty at the start and its block size is 64bytes. Assume that the number of iterations of this loop is extremely large (the number of components to add is in the millions).

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At first let the latency of an L1 miss be 30 clocks. Remember that the LW is first tried in the cache. If it misses, the pipeline "freezes" for 30 clocks and then the pipeline is restarted.

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We examine the efficiency of this loop on the 5-stage pipeline with a blocking and a nonblocking data cache. The branch flushes the I-fetch and I-decode stages whenever it is taken.

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At first let the latency of an L1 miss be 30 clocks. Remember that the LW is first tried in the cache. If it misses, the pipeline "freezes" for 30 clocks and then the pipeline is restarted.

Problem 4.8 (Part-a)

Consider first that the cache is blocking. Find the average execution time (in cycles) of each iteration of the loop (i.e., the average time taken by each accumulation) as a function of the stride.

Problem 4.8 (Execution times for Hit & Miss cases)

In Case of a Hit

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

Problem 4.8 (Execution times for Hit & Miss cases)

In Case of a Hit

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 6

In Case of a miss

Problem 4.8 (Execution times for Hit & Miss cases)

In Case of a Hit

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 6

In Case of a miss

LOOP:	LW R4,0(R3)	1 cycle

Execution Time for Miss Iteration = 37

Problem 4.8 (Execution times for Hit & Miss cases)

In Case of a Hit

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 6

In Case of a miss

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle

Execution Time for Miss Iteration = 37

Problem 4.8 (Execution times for Hit & Miss cases)

In Case of a Hit

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 6

In Case of a miss

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle + 30 cache latency + 1 retry

Execution Time for Miss Iteration = 37

Problem 4.8 (Execution times for Hit & Miss cases)

In Case of a Hit

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 6

In Case of a miss

LOOP:	LW R4,0(R3)	1 cycle
	ADDI R3,R3,stridex4	1 cycle
	ADD R1,R1,R4	1 cycle + 30 cache latency + 1 retry
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	ADDI R3,R3,stridex4	1 cycle
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Execution Time for Hit Iteration = 6

In Case of a miss

LOOP:	LW R4,0(R3)	1 cycle
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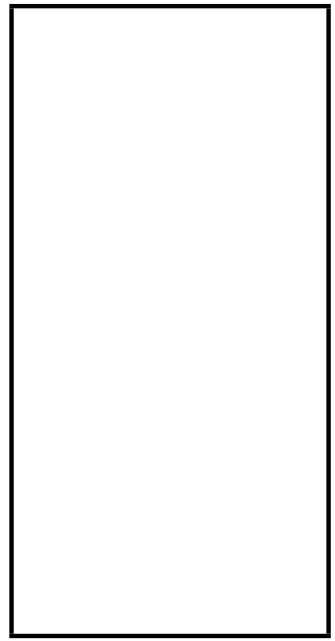
	BNE R3,R5,LOOP	1 cycle + 2 cycle for pipeline flush

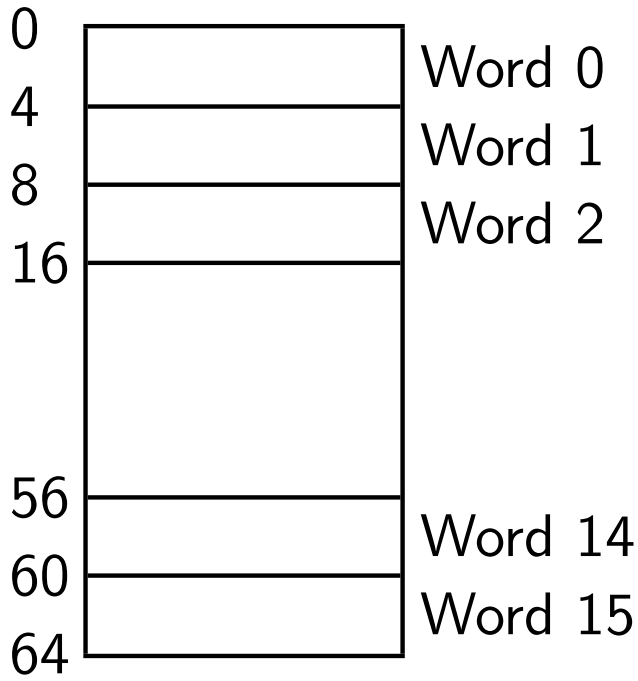
Execution Time for Miss Iteration = 37

Problem 4.8(Hit Rate)



64-Byte Block

Problem 4.8(Hit Rate)



64-Byte Block

Problem 4.8

```
LOOP :
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```
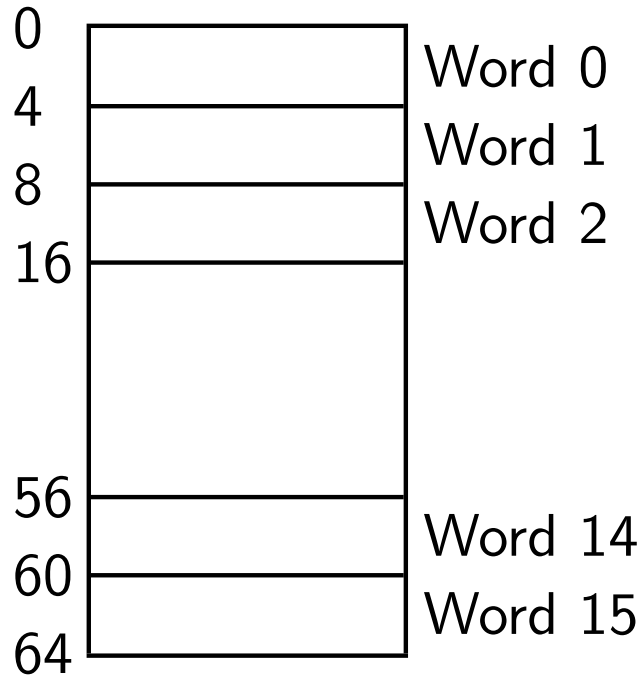
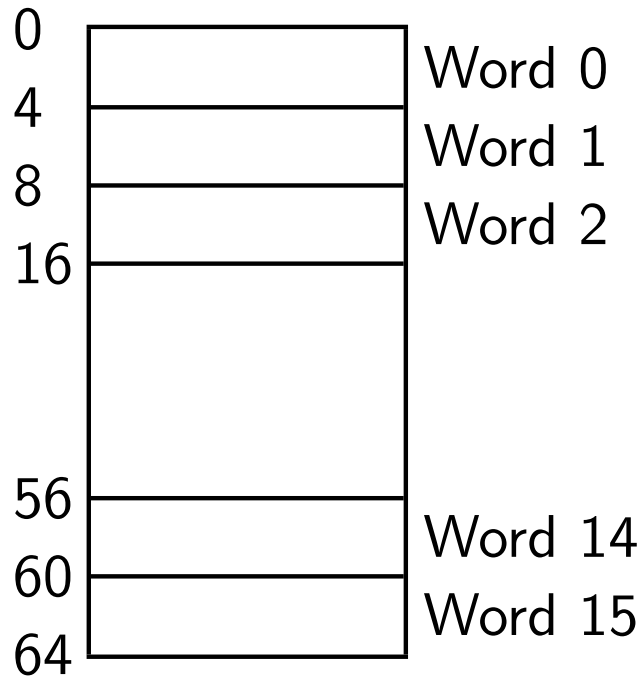



Problem 4.8

Stride = 1

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,4
ADD R1,R1,R4
BNE R3,R5,LOOP
```



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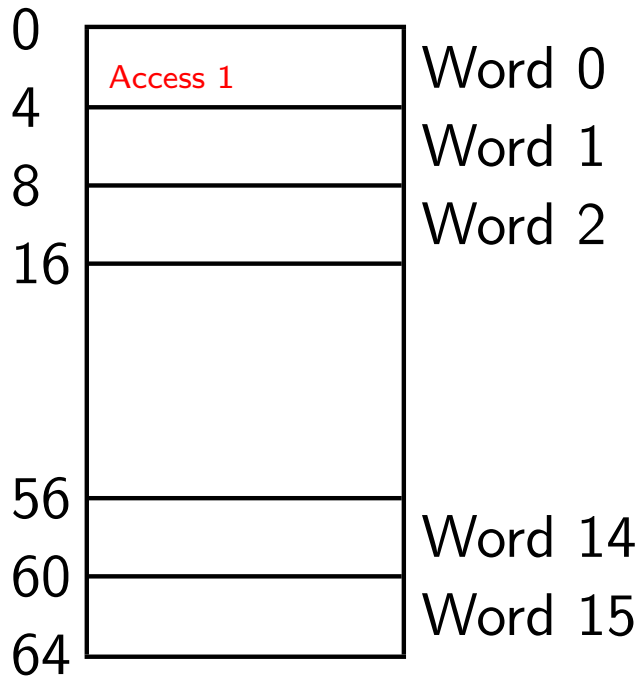

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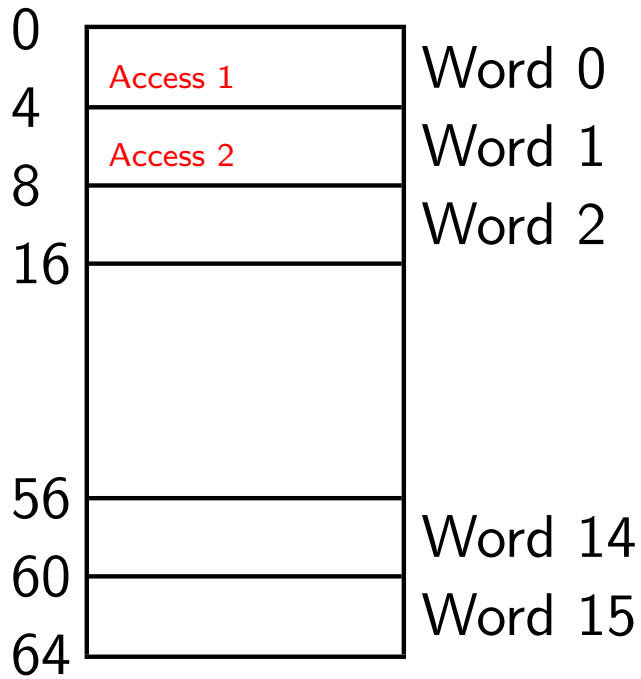

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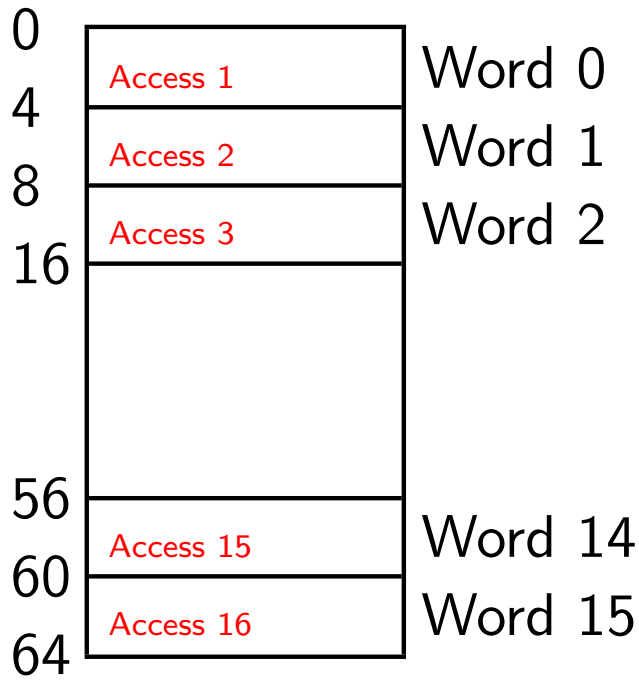

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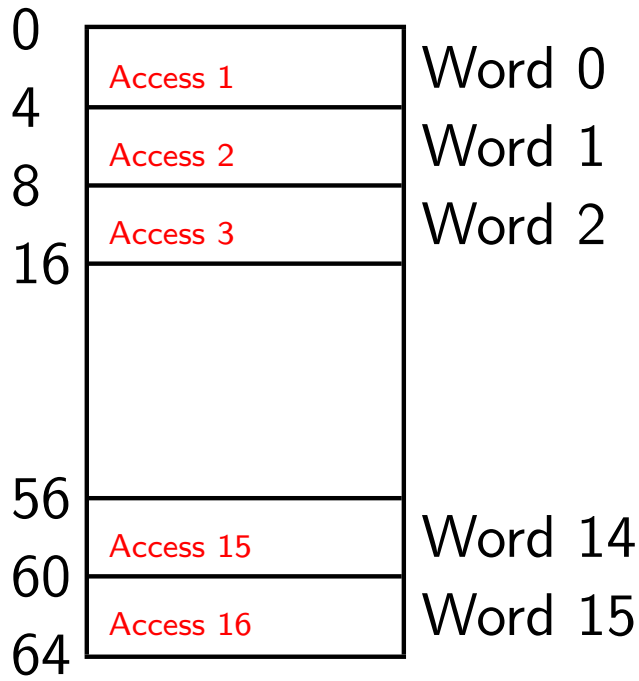

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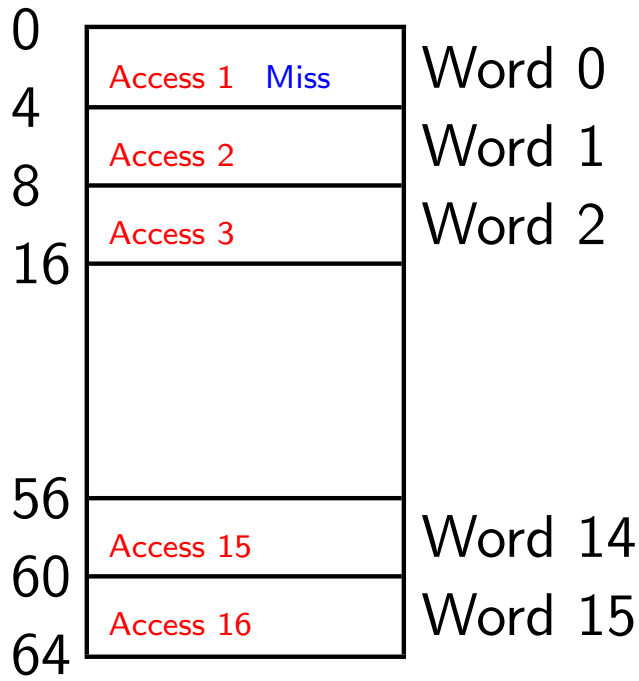

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ADDI R3,R3,4
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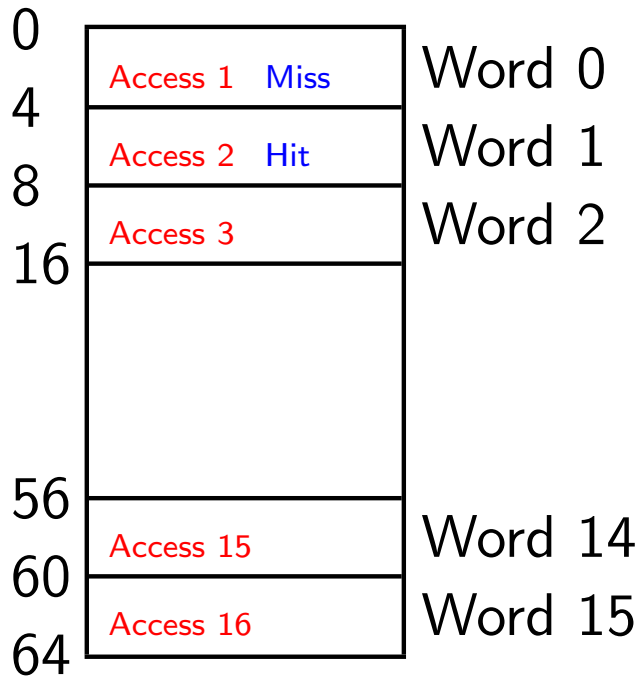

Problem 4.8

Stride = 1

```
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LW R4,0(R3)
ADDI R3,R3,4
ADD R1,R1,R4
BNE R3,R5,LOOP
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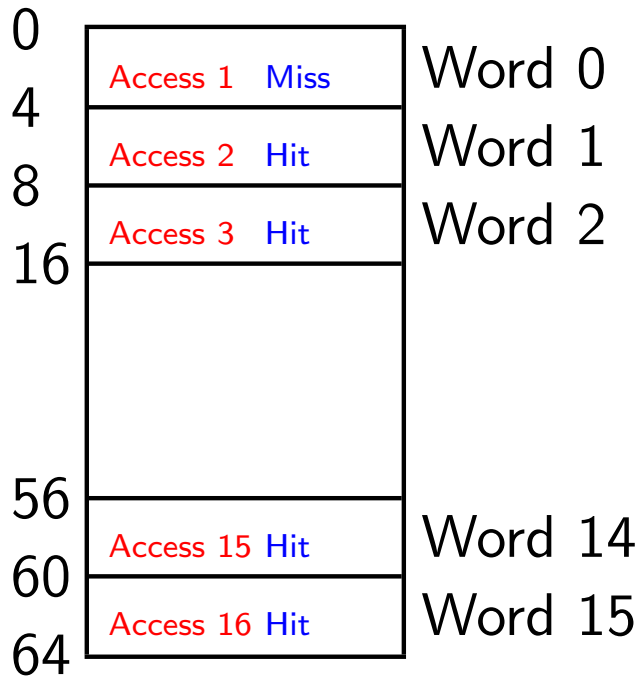

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```
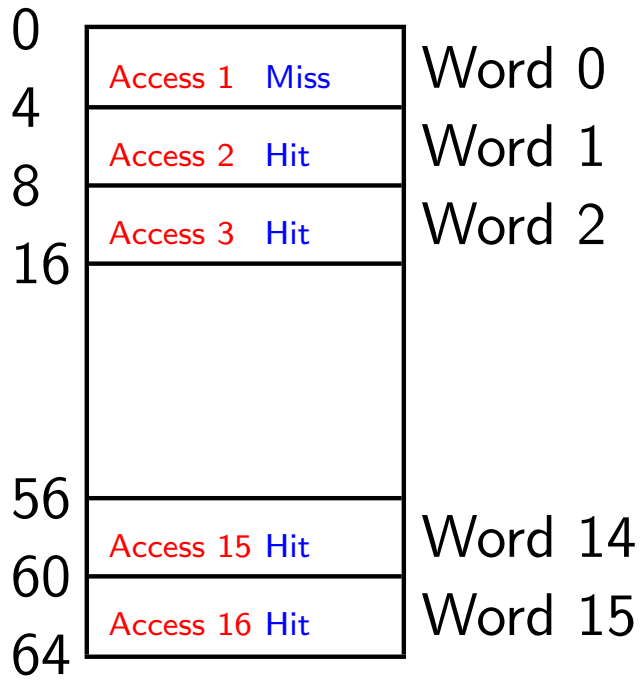
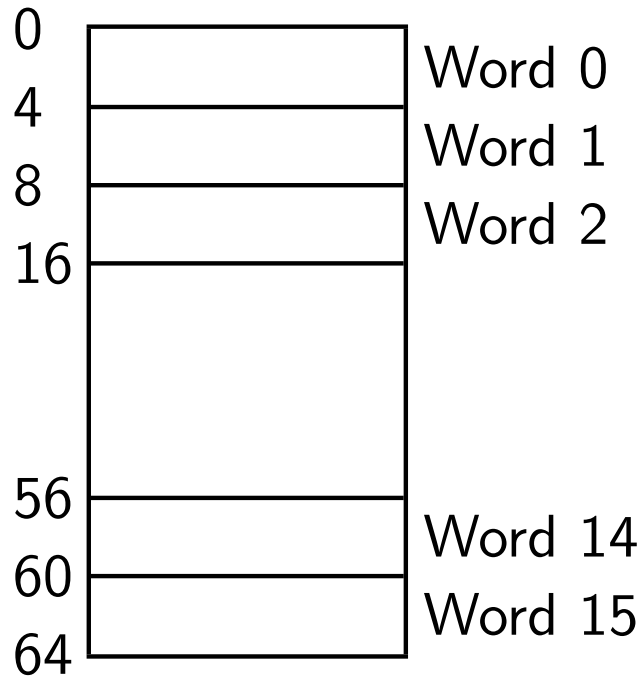



1 miss and 15 Hits

Problem 4.8

Stride = 2

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,8
ADD R1,R1,R4
BNE R3,R5,LOOP
```



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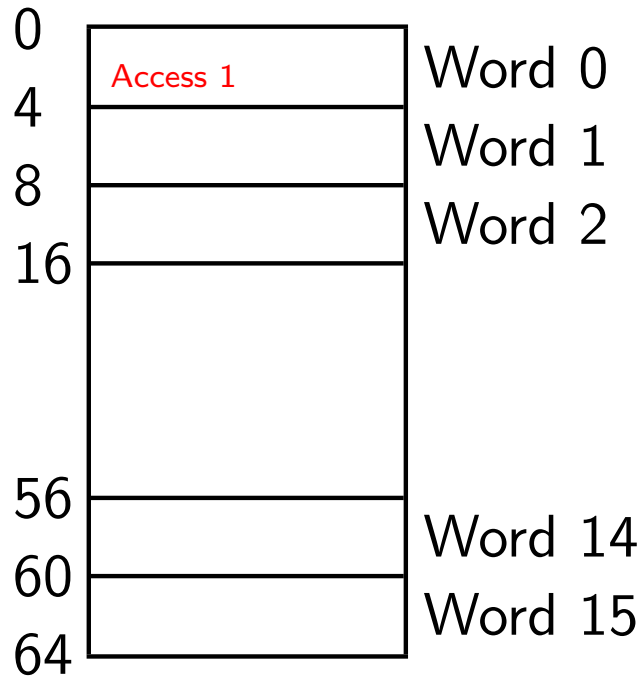

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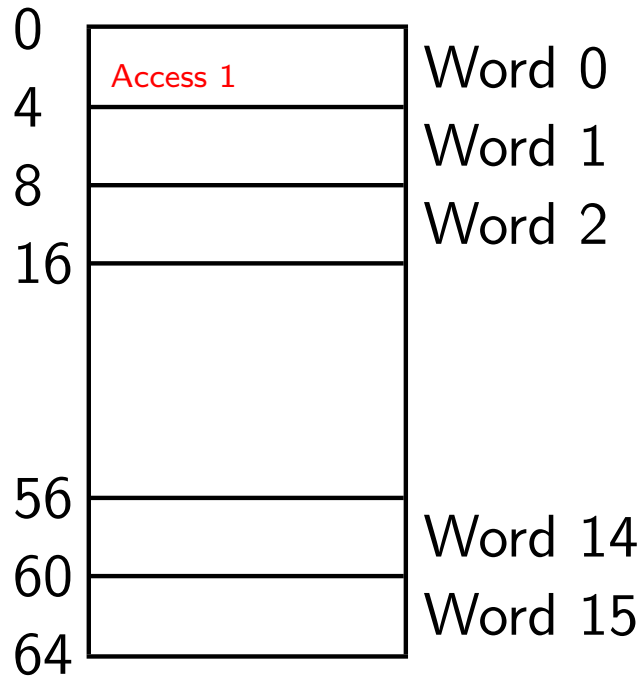

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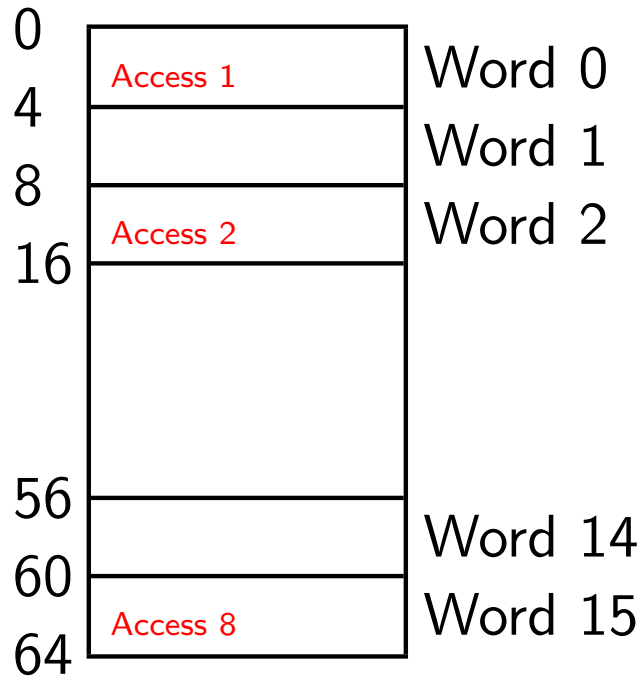

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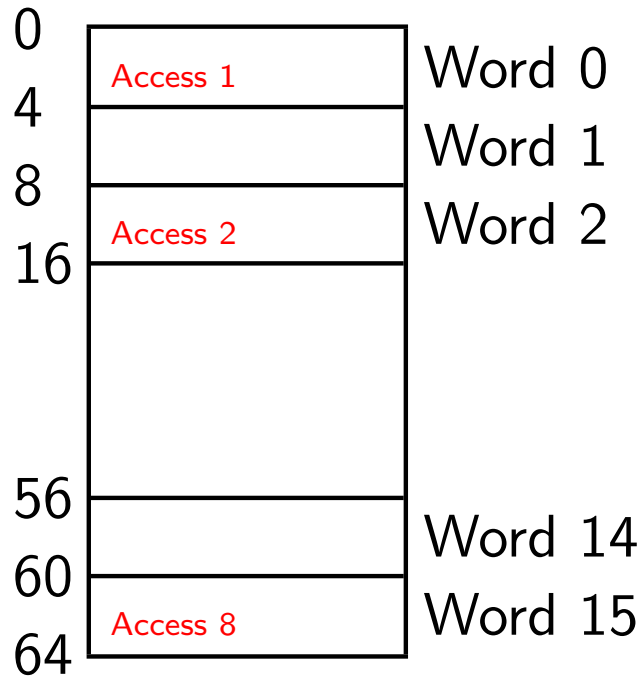

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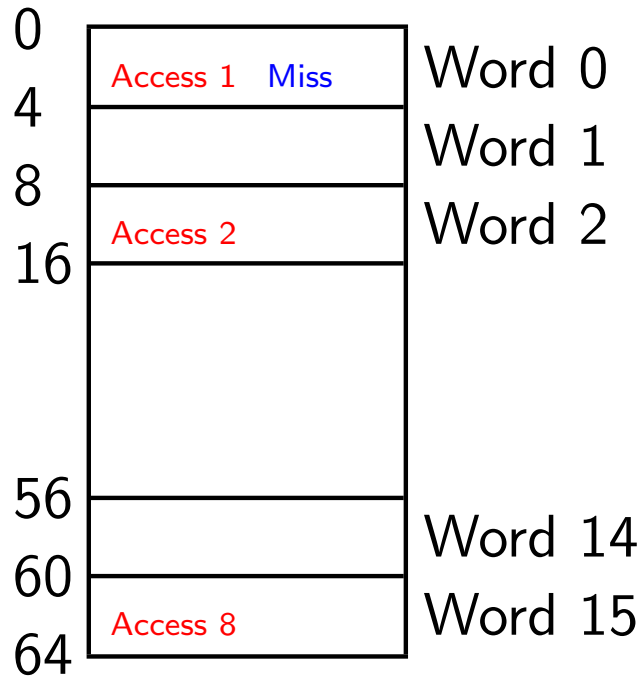

Problem 4.8

Stride = 2

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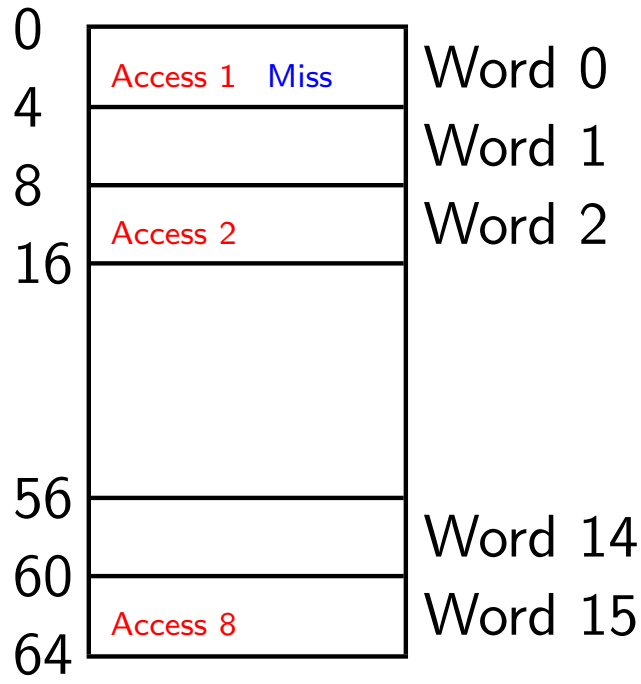

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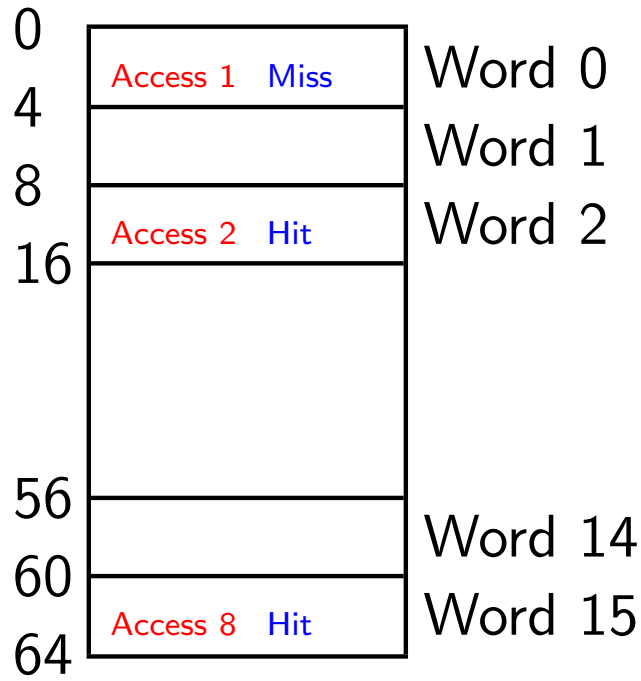

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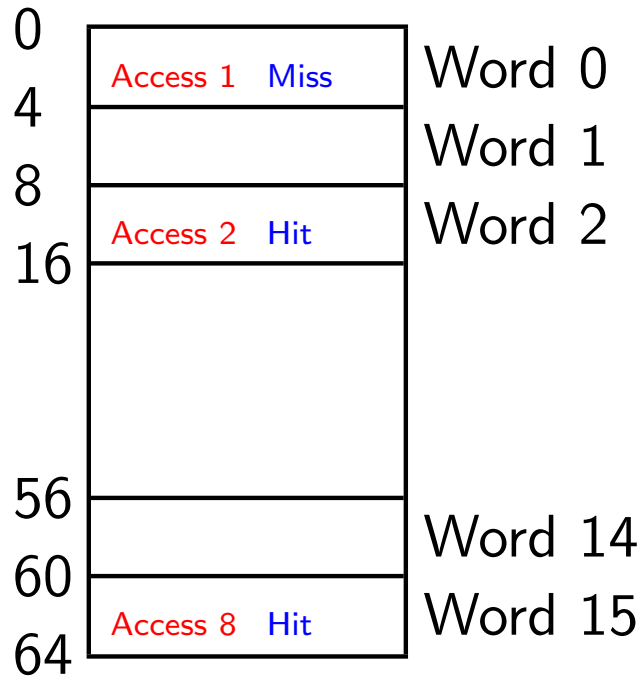
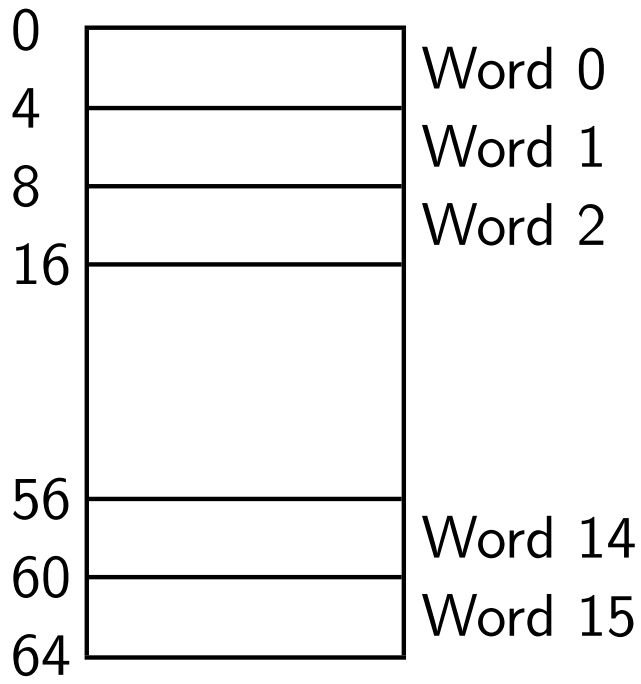


1 miss and 7 Hits

Problem 4.8

Stride = 16

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,64
ADD R1,R1,R4
BNE R3,R5,LOOP
```



Problem 4.8

Stride = 16

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,64
ADD R1,R1,R4
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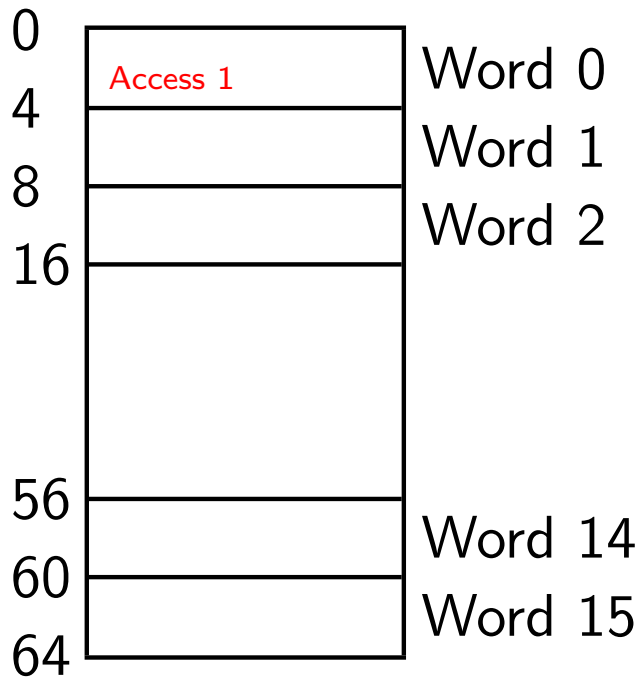

Problem 4.8

Stride = 16

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,64
ADD R1,R1,R4
BNE R3,R5,LOOP
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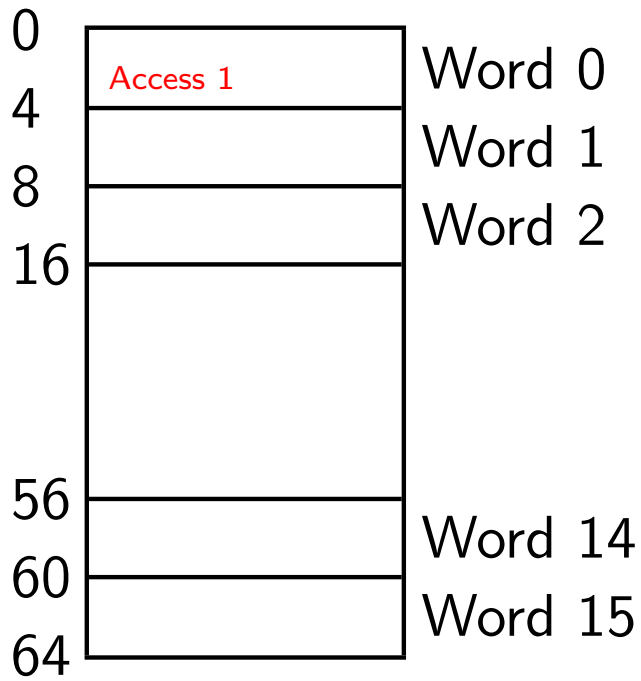

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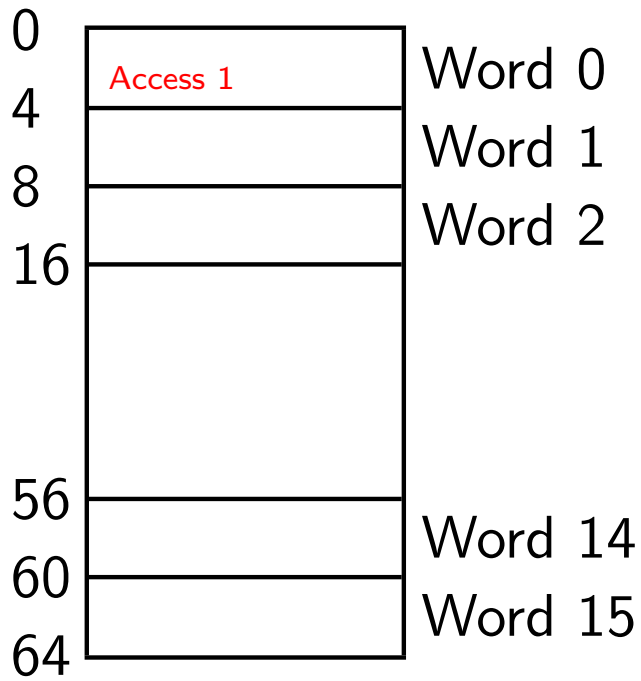

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Stride = 16

```
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BNE R3,R5,LOOP
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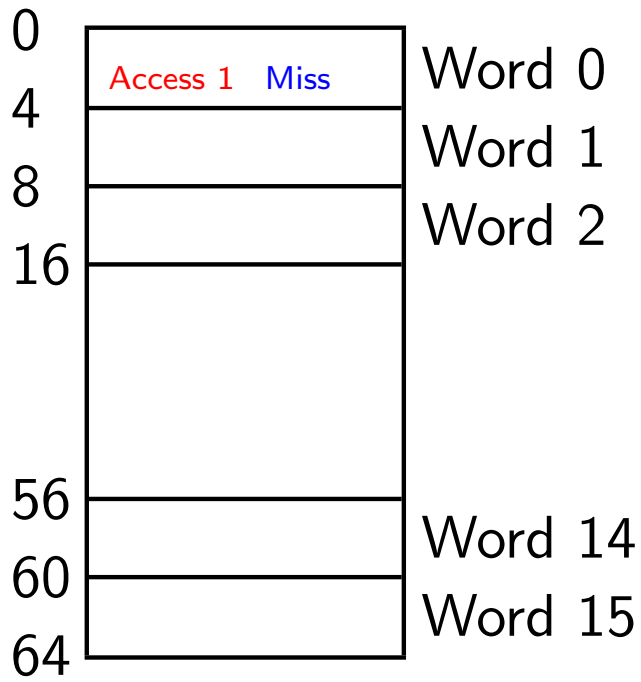
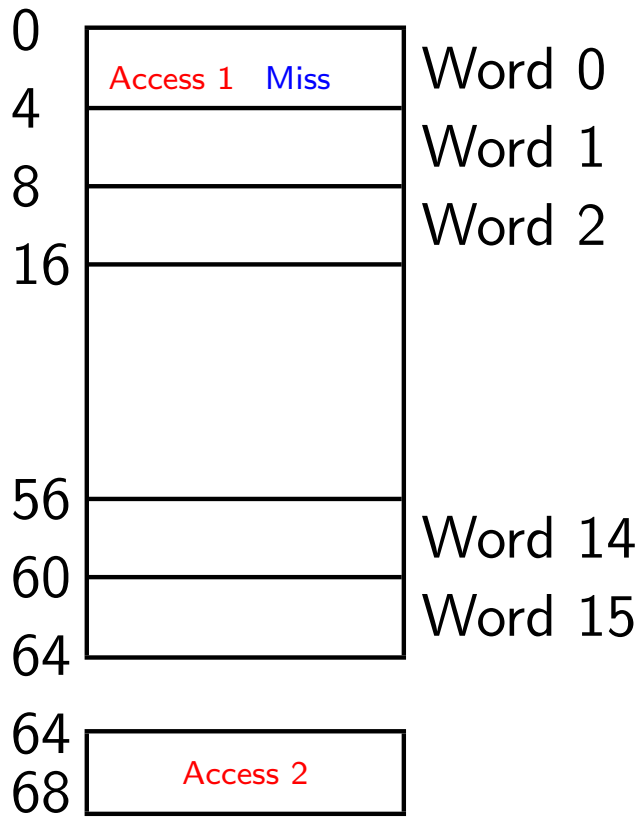


Problem 4.8

Stride = 16

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,64
ADD R1,R1,R4
BNE R3,R5,LOOP
```



Problem 4.8

Stride = 16

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,64
ADD R1,R1,R4
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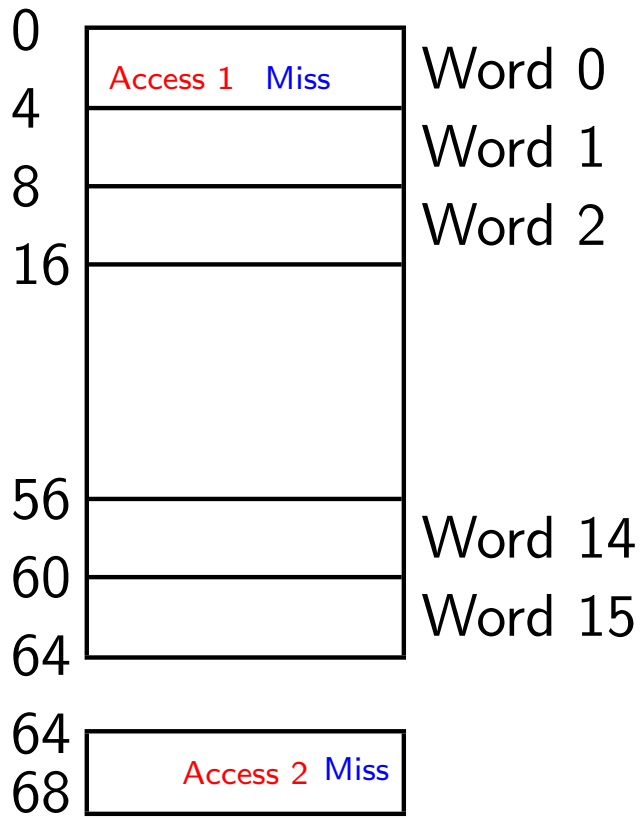
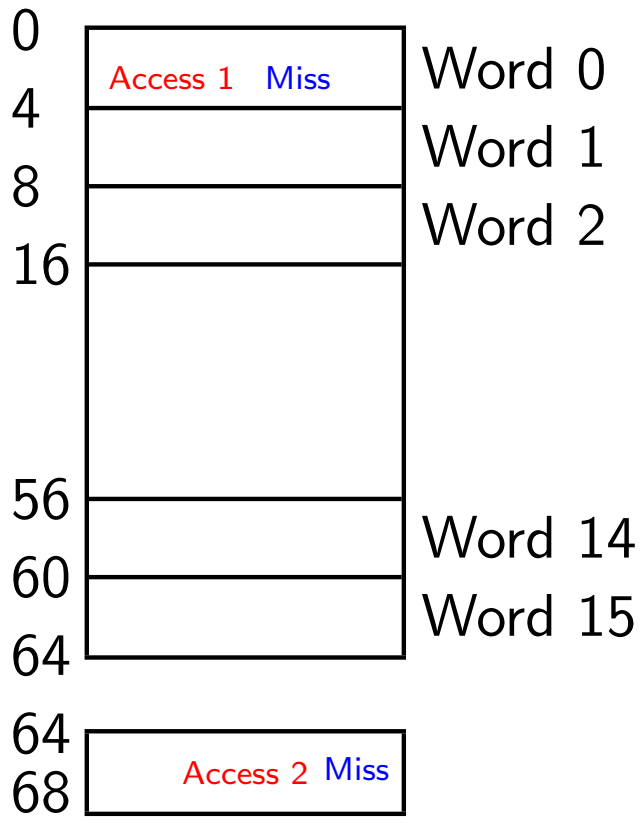


Problem 4.8

Stride = 16

```
LOOP :
LW R4,0(R3)
ADDI R3,R3,64
ADD R1,R1,R4
BNE R3,R5,LOOP
```



All Accesses will miss

Problem 4.8

Stride >= 16

Problem 4.8

Stride >= 16

We always miss

Problem 4.8

Stride >= 16

We always miss

Average Execution time = 37 cycles

Problem 4.8

Stride < 16

Problem 4.8

Stride < 16

Amount of memory spanned between two consecutive accesses.

Problem 4.8

Stride < 16

Amount of memory spanned between two consecutive accesses. $=$ LCM(16,stride)

Problem 4.8

Stride < 16

Amount of memory spanned between two consecutive accesses. $=$ LCM(16,stride)

Number of accesses to single block $= \frac{LCM(16,stride)}{stride}$

Problem 4.8

Stride < 16

Amount of memory spanned between two consecutive accesses. = LCM(16,stride)

Number of accesses to single block $= \frac{LCM(16,stride)}{stride}$

Number of misses $= \frac{LCM(16,stride)}{16}$

Problem 4.8

$$\text{Avergae execution Time} = \frac{Misses * 37 + Hits * 6}{Accesses}$$

Problem 4.8

$$\text{Avergae execution Time} = \frac{Misses*37+Hits*6}{Accesses}$$

$$\text{Avergae execution Time} = \frac{Misses*37+(Accesses-Misses)*6}{Accesses}$$

Problem 4.8

$$\text{Avergae execution Time} = \frac{Misses*37+Hits*6}{Accesses}$$

$$\text{Avergae execution Time} = \frac{Misses*37+(Accesses-Misses)*6}{Accesses}$$

$$\text{Avergae execution Time} = \frac{\frac{LCM(16,stride)}{16}*37+(\frac{LCM(16,stride)}{stride}-\frac{LCM(16,stride)}{16})*6}{\frac{LCM(16,stride)}{stride}}$$

Problem 4.8

$$\text{Avergae execution Time} = \frac{Misses*37+Hits*6}{Accesses}$$

$$\text{Avergae execution Time} = \frac{Misses*37+(Accesses-Misses)*6}{Accesses}$$

$$\text{Avergae execution Time} = \frac{\frac{LCM(16,stride)}{16}*37+(\frac{LCM(16,stride)}{stride}-\frac{LCM(16,stride)}{16})*6}{\frac{LCM(16,stride)}{stride}}$$

$$\text{Avergae execution Time} = \frac{37*stride}{16}+6-\frac{6*stride}{16} = \frac{31}{16}*stride+6$$

Problem 4.8 (Part b)

```
LOOP :
LW R4,0(R3)
PW stridex4(R3)
ADDI R3,R3,stridex4
ADD R1,R1,R4
BNE R3,R5,LOOP
```

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle

Execution Time for Miss Iteration = 37+1-6= 32

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle

Execution Time for Miss Iteration = 37+1-6= 32

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle

Execution Time for Miss Iteration = 37+1-6= 32

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In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
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Problem 4.8 (Execution times for Hit & Miss)

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LOOP:	LW R4,0(R3)	1-cycle
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	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle + 30 + 1

Execution Time for Miss Iteration = 37+1-6= 32

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle + 30 + 1- 6

Execution Time for Miss Iteration = 37+1-6= 32

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle + 30 + 1- 6
	BNE R3,R5,LOOP	1-cycle

Execution Time for Miss Iteration = 37+1-6= 32

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle + 30 + 1- 6
	BNE R3,R5,LOOP	1-cycle + 2-cycle for pipeline flush

Problem 4.8 (Execution times for Hit & Miss)

In Case of a Hit !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
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	ADD R1,R1,R4	1-cycle
	BNE R3,R5,LOOP	1-cycle + 2 cycle for pipeline flush

Execution Time for Hit Iteration = 7

In Case of a miss !

LOOP:	LW R4,0(R3)	1-cycle
	PW stridex4(R3)	1-cycle
	ADDI R3,R3,stridex4	1-cycle
	ADD R1,R1,R4	1-cycle + 30 + 1- 6
	BNE R3,R5,LOOP	1-cycle + 2-cycle for pipeline flush

Execution Time for Miss Iteration = 37+1-6= 32

Problem 4.8 (Part-b)

Stride >= 16

Problem 4.8 (Part-b)

Stride >= 16

We always miss

Problem 4.8 (Part-b)

Stride >= 16

We always miss

Average Execution time = 32 cycles

Problem 4.8(Part-b)

Stride < 16

Problem 4.8(Part-b)

Stride < 16

Avergae execution Time $= \frac{Misses*32+Hits*7}{Accesses}$

Problem 4.8(Part-b)

Stride < 16

Avergae execution Time $= \frac{Misses*32+Hits*7}{Accesses}$

Avergae execution Time $= \frac{Misses*32+(Accesses-Misses)*7}{Accesses}$

Problem 4.8(Part-b)

Stride < 16

$$\text{Avergae execution Time} = \frac{Misses*32+Hits*7}{Accesses}$$

$$\text{Avergae execution Time} = \frac{Misses*32+(Accesses-Misses)*7}{Accesses}$$

$$\text{Avergae execution Time} = \frac{\frac{LCM(16,stride)}{16}*32+(\frac{LCM(16,stride)}{stride}-\frac{LCM(16,stride)}{16})*7}{\frac{LCM(16,stride)}{stride}}$$

Problem 4.8(Part-b)

Stride < 16

$$\text{Avergae execution Time} = \frac{Misses*32+Hits*7}{Accesses}$$

$$\text{Avergae execution Time} = \frac{Misses*32+(Accesses-Misses)*7}{Accesses}$$

$$\text{Avergae execution Time} = \frac{\frac{LCM(16,stride)}{16}*32+(\frac{LCM(16,stride)}{stride}-\frac{LCM(16,stride)}{16})*7}{\frac{LCM(16,stride)}{stride}}$$

$$\text{Avergae execution Time} = \frac{25}{16} * stride + 7$$

Problem 4.8 (Part-c)

Is it possible to find out when the prefetch is effective, as a function of the stride, the block size and the miss latency? What is the breakeven point in general?

Problem 4.8 (Part-c)

Stride $>= 16$

Problem 4.8 (Part-c)

Stride >= 16

We always miss

Problem 4.8 (Part-c)

Stride $>= 16$

We always miss

prefetch is always more effective

Problem 4.8 (Part-c)

Stride < 16

Problem 4.8 (Part-c)

Stride < 16

Avergae execution Time with prefecth $<$ Avergae execution Time with out prefech

Problem 4.8 (Part-c)

Stride < 16

Avergae execution Time with prefecth $<$ Avergae execution Time with out prefech

$\frac{25}{16} * stride + 7 < \frac{31}{16} * stride + 6$

Problem 4.8 (Part-c)

Stride < 16

Avergae execution Time with prefecth $<$ Avergae execution Time with out prefech

$\frac{25}{16} * stride + 7 < \frac{31}{16} * stride + 6$

$stride >= 3$