8 Prefetching [45 points]

An ETH student writes two programs A and B and runs them on 3 different toy machines, M1, M2, and M3, to determine the type of the prefetching mechanism used in each of these 3 machines. She observes programs A and B to have the following access patterns to cache blocks. Note that the addresses are *cache block addresses*, not byte addresses.

Program A: 27 accesses

```
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64,
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64,
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64
```

Program B: 501 accesses

```
b, b + 2, b + 4, ...., b + 998, b + 1000
```

The student is able to measure the accuracy and coverage of the prefetching mechanism in each of the machines. The following table shows her measurement results:

	Machine M1		**Machine M2**		**Machine M3**	
	Coverage	Accuracy	Coverage	Accuracy	Coverage	Accuracy
Program A	6/27	6/27	0	0	1/3	9/26
Program B	499/501	499/501	0	0	499/501	499/500

The student knows the following facts about M1, M2, and M3 machines:

- The prefetcher prefetches into a fully-associative cache whose size is 8 cache blocks. The cache employs the FIFO (First-In First-Out) replacement policy.
- The prefetchers have large enough resources to detect and store access patterns.
- Each cache block access is separated long enough in time such that all prefetches issued can complete before the next access happens.
- There are 5 different possible choices for the prefetching mechanism:
  1) Markov prefetcher with a correlation table of 4 entries
  2) Markov prefetcher with a correlation table of 10 entries
  3) 1st-next-block prefetcher (degree = 1) – prefetches block N + 1 after seeing block N
  4) 4th-next-block prefetcher (degree = 1) – prefetches block N + 4 after seeing block N
  5) stride prefetcher
- None of the above-mentioned prefetchers employ confidence bits.
- The prefetchers start out with an empty table when each program A and B start execution.
- The prefetcher sends only one prefetch request after a program access (i.e., prefetch degree = 1).

Determine what type of prefetching mechanism each of the above-mentioned machines use:

Machine M1: 4th-next-block prefetcher

Machine M2: Markov prefetcher with a correlation table of 4 entries

Machine M3: Stride prefetcher

Extra space for explanation:

We calculate the accuracy and coverage for all 5 types of prefetchers, and then we can answer what prefetcher each machine is using:

The 5 prefetechers work in the following ways when running Application A:

Markov, table size=4: Coverage: 0, Accuracy: 0
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64,
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64,
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64,

Markov, table size=10: Coverage: 17/27, Accuracy: 17/18
a, a + 1, a + 2, a + 3, a + 4, a + 8, a + 16, a + 32, a + 64,
a, $\underline{a + 1}$, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, $\underline{a + 8}$, $\underline{a + 16}$, $\underline{a + 32}$, $\underline{a + 64}$,
$\underline{a}$, $\underline{a + 1}$, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, $\underline{a + 8}$, $\underline{a + 16}$, $\underline{a + 32}$, $\underline{a + 64}$ |unused: a

1st-next-block: Coverage: 4/9, Accuracy: 4/9
a, $\underline{a + 1}$, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, a + 8, a + 16, a + 32, a + 64, |unused: a + 5, a + 9, a + 17, a + 33, a + 65,
a, $\underline{a + 1}$, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, a + 8, a + 16, a + 32, a + 64, |unused: a + 5, a + 9, a + 17, a + 33, a + 65,
a, $\underline{a + 1}$, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, a + 8, a + 16, a + 32, a + 64 |unused: a + 5, a + 9, a + 17, a + 33, a + 65

4th-next-block: Coverage: 6/27, Accuracy: 6/27
a, a + 1, a + 2, a + 3, $\underline{a + 4}$, $\underline{a + 8}$, a + 16, a + 32, a + 64,|unused: a + 5, a + 6, a + 7, a + 12, a + 20, a + 36, a + 68,
a, a + 1, a + 2, a + 3, $\underline{a + 4}$, $\underline{a + 8}$, a + 16, a + 32, a + 64,|unused: a + 5, a + 6, a + 7, a + 12, a + 20, a + 36, a + 68,
a, a + 1, a + 2, a + 3, $\underline{a + 4,}$ $\underline{a + 8}$, a + 16, a + 32, a + 64|unused: a + 5, a + 6, a + 7, a + 12, a + 20, a + 36, a + 68

Stride: Coverage: 1/3, Accuracy: 9/26
a, a + 1, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, a + 8, a + 16, a + 32, a + 64, |unused: a + 5, a + 12, a + 24, a + 48, a + 96,
a, a + 1, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, a + 8, a + 16, a + 32, a + 64, |unused: a - 64, a + 5, a + 12, a + 24, a + 48, a + 96,
a, a + 1, $\underline{a + 2}$, $\underline{a + 3}$, $\underline{a + 4}$, a + 8, a + 16, a + 32, a + 64 |unused: a - 64, a + 5, a + 12, a + 24, a + 48, a + 96

The 5 prefetechers work in the following ways when running Application B:

Markov, table size=4: Coverage: 0, Accuracy: 0
b, b + 2, b + 4, b + 6, b + 8, b + 10, ... , b + 998, b + 1000

Markov, table size=10: Coverage: 0, Accuracy: 0
b, b + 2, b + 4, b + 6, b + 8, b + 10, ... , b + 998, b + 1000

1st-next-block: Coverage: 0, Accuracy: 0
b, b + 2, b + 4, b + 6, b + 8, b + 10, ... , b + 998, b + 1000 |unused: b + 1, b + 3, ..., b + 999, b + 1001

4th-next-block: Coverage: 499/501, Accuracy: 499/501
b, b + 2, $\underline{b + 4}$, $\underline{b + 6}$, $\underline{b + 8}$, $\underline{b + 10}$, ..., $\underline{b + 998}$, $\underline{b + 1000}$ |unused: b +1002, b + 1004

Stride: Coverage: 499/501, Accuracy: 499/500
b, b + 2, $\underline{b + 4}$, $\underline{b + 6}$, $\underline{b + 8}$, $\underline{b + 10}$, ..., $\underline{b + 998}$, $\underline{b + 1000}$ |unused: b + 1002