7 Branch Prediction [60 points]

Consider the following high level language code segment:

```
int array[1000] = { /* random values */ };
int sum1 = 0, sum2 = 0, sum3 = 0, sum4 = 0;

for (i = 0; i < 1000; i ++)      // Branch 1: Loop Branch
{
    // Branch 1: Taken
    if (i % 2 == 0)              // Branch 2: If Condition 1
        // Branch 2: Taken
        if (i % 3 == 0)          // Branch 3: If Condition 2
            sum1 += array[i];    // Branch 3: Taken
        else
            sum2 += array[i];
    else
        if (i % 4 == 0)          // Branch 4: If Condition 3
            sum3 += array[i];    // Branch 4: Taken
        else
            sum4 += array[i];
}
```

(a) [20 points] What is the prediction accuracy for each of the four branches using a per-branch last-time predictor (assume that every per-branch counter starts at "not-taken")? Please show all of your work.

Branch 1:

999/1001. The branch is mispredicted the first and last time it's executed.

Branch 2:

$0/1000 \times 100 = 0\%$. The branch changes direction every time it's executed.

Branch 3:

33.2%. The pattern repeats Miss, Miss, Hit

Branch 4:

100%. The branch is never taken.

(b) [20 points] What is the prediction accuracy for each of the four branches when a per-branch 2-bit saturating counter-based predictor is used (assume that every per-branch counter starts at "strongly not-taken")? Please show all of your work.

Branch 1:

998/1001. The branch is mispredicted the first two times and last time it's executed.

Branch 2:

$500/1000 \times 100 = 50\%$. The counter changes between "strongly not-taken" to "weakly not-taken" every iteration. Branch is taken every other time.

Branch 3:

66.6%. The pattern repeats Miss, Hit, Hit

Branch 4:

100%. The branch is never taken.

(c) [20 points] What is the prediction accuracy for both Branch 2 and Branch 3, when the counter starts at (i) "weakly not-taken" and (ii) "weakly taken"?

Branch 2 (i)

(i) 0%. The counter alternates between "weakly not-taken" and "weakly taken" missing on each

Branch 2 (ii)

(ii) 50%. The counter alternates between "weakly taken" and "strongly taken" hitting every other

Branch 3 (i)

(i) 66.8%. Miss, Hit, Hit repeats

Branch 3 (ii)

(ii) 66.2%. After the predictor settles to "strongly not-taken", the pattern repeats Miss, Hit, Hit