

### 3. Branch Prediction [50 points]

Assume the following piece of code that iterates through two large arrays, *j* and *k*, each populated with completely (i.e., truly) random positive integers. The code has two branches (labeled B1 and B2). When we say that a branch is *taken*, we mean that the code *inside* the curly brackets is executed. Assume the code is run to completion without any errors (there are no exceptions). For the following questions, assume that this is the only block of code that will ever be run, and the loop-condition branch (B1) is resolved first in the iteration before the if-condition branch (B2).

```
for (int i = 0; i < 1000000; i++) {      /* B1 */
    /* TAKEN PATH for B1 */
    if (i % 3 == 0) {                    /* B2 */
        /* TAKEN PATH for B2 */
        j[i] = k[i] - i;
    }
}
```

You are running the above code on a machine with a two-bit global history register (GHR) shared by all branches, which starts with *Not Taken*, *Not Taken* (2'b00). Each pattern history table entry (PHTE) contains a 2-bit saturating counter.

The saturating counter values are as follows:

2'b00 - Strongly Not Taken

2'b01 - Weakly Not Taken

2'b10 - Weakly Taken

2'b11 - Strongly Taken

- (a) You observe that the branch predictor mispredicts 100% of the time in the first 5 iterations of the loop. Is this possible? Fill in the table below with all possible initial values each entry can take. Leave the table blank if this is not possible.

**PHT**

PHT Entry	Value
TT	01
TN	00
NT	01
NN	00 or 01

Show your work here:

The pattern after 5 iterations: TTTNTNTTTN.

- For GHR=NN, the only observed branch is T, which is the first taken branch. Therefore, the PHTE for NN has to be either 00 or 01 so that the branch predictor mispredicts the taken branch.
- For GHR=TT, the observed branches are T N T N. The PHTE for TT has to be initialized to 01 in order to cause the predictor to always mispredict.
- For GHR=TN, the observed branches are T T. Thus, the initial PHTE value for TN has to be 00 to mispredict both taken branches.
- For GHR=NT, the observed branches are T (i.e., the second taken branch) N T. Similar to the TT entry, NT's PHTE has to be initialized 01.

Initials: \_\_\_\_\_

(b) *Please read the entire question first before answering any part.*

Rachata believes that the misprediction rate can become 0% during the steady state.

Is this possible?

Circle one: YES

☒ NO

If it is possible (YES), fill in one possible set of initial PHT values that can lead to a 0% misprediction rate.

PHT	
PHT Entry	Value
TT	
TN	
NT	
NN	

If it is not possible (NO), what is the lowest misprediction rate that can be achieved during the steady state?

The lowest misprediction rate is 33.33%.

Show all your work here below:

No, it's not possible. The best correct prediction rate is 4/6, which is 1/3 misprediction rate.

At steady state, we will keep observing the following pattern which repeats over time: TTTNTN.

With GHR=TN, this entry will saturate to 11, taken all the time. Therefore, 2 Ts will be always predicted correctly out of the 6 branches in the pattern.

With GHR=NT or TT, the predictor will observe either T and N. No matter what the initial values are for these two entries, only one of the branches can be predicted correctly. Therefore 2 out of of remaining 4 branches in the pattern will be predicted correctly.

With GHR=NN, the predictor won't observe it during the steady state.