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Branch Simulator
Project 2

CMPEN 431

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1. Describe in 100 words or less how the provided simulator enables testing various branch predictions.

The Branch Predictor Simulator is built to test and compare various branch prediction methods, like Static, One-Bit, Two-Bit, Bimodal, GShare, and Hybrid. It works with custom or generated branch traces, simulating predictions, comparing them to actual outcomes, and updating the predictor's behavior as it goes. It tracks accuracy in real time, logs detailed stats, and keeps a record of updates to the Branch History Table (BHT). By running predictors through different scenarios—randomized outcomes, patterns, or correlations—it helps highlight the strengths and weaknesses of each, giving clear insights into branch prediction performance.

2. Table with the overall accuracy of each predictor of the generated trace file

The first table below shows the cumulative accuracy of each branch predictor as it iterates across 10,000 branches, while the second one shows the overall accuracy after 10,000 branches:

Table 1: Cumulative Accuracy

Predictor	Branches Processed	Cumulative Accuracy (%)
Static Taken	10,000	50.04
Static Not Taken	10,000	49.96
One Bit	10,000	50.05
Two Bit	10,000	50.1
Bimodal	10,000	50.12
GShare	10,000	49.56
Hybrid	10,000	49.99

Table 2: Overall Accuracy

Predictor	Total Branches Processed	Overall Accuracy (%)
Static Taken	10,000	50.04
Static Not Taken	10,000	49.96
One Bit	10,000	50.05
Two Bit	10,000	50.1
Bimodal	10,000	50.12
GShare	10,000	49.56
Hybrid	10,000	49.99

To get this data, I ran the following commands using the seed as my ID number (946395620):

```
F:\common branch predictors\Project2_Solution>python branch_trace_generator.py --trace branch_trace.csv
 --branches 10000 --seed 946395620

F:\common branch predictors\Project2_Solution>python branch_simulator.py --trace branch_trace.csv --x 1
0 --fast
```

Additional Testing (Not Required, but recommended by TA)

The results can be analyzed in terms of static predictors, so we can check if the amount of taken branches and not taken branches are inverses of each other but also add up to a 100%.

```
Static Taken, 5100, 50.588235294117645
Static Not Taken, 5100, 49.411764705882355
```

It means that Static Taken predicts ~50.59% and Static Not Taken predicts ~49.41% which is what I would expect, as they add to a 100%.

Additional tests were done through my own customTrace.csv was run to analyze why I kept getting ~50% accuracy which I was recommended to test by the TA (Saleh) to ensure that at least my code was running well.

	A	B
1	BranchAddress	Outcome
2	28195	0
3	61137	1
4	54517	1
5	51127	1
6	61850	0
7	8343	1
8	34768	0
9	42110	1
10	44142	0
11	49480	0
12		

Results in:

Table 3: Cumulative Accuracy of Custom Trace

Predictor	Branches Processed	Cumulative Accuracy (%)
Static Taken	10	50
Static Not Taken	10	50
One Bit	10	50
Two Bit	10	50
Bimodal	10	50
GShare	10	50
Hybrid	10	50

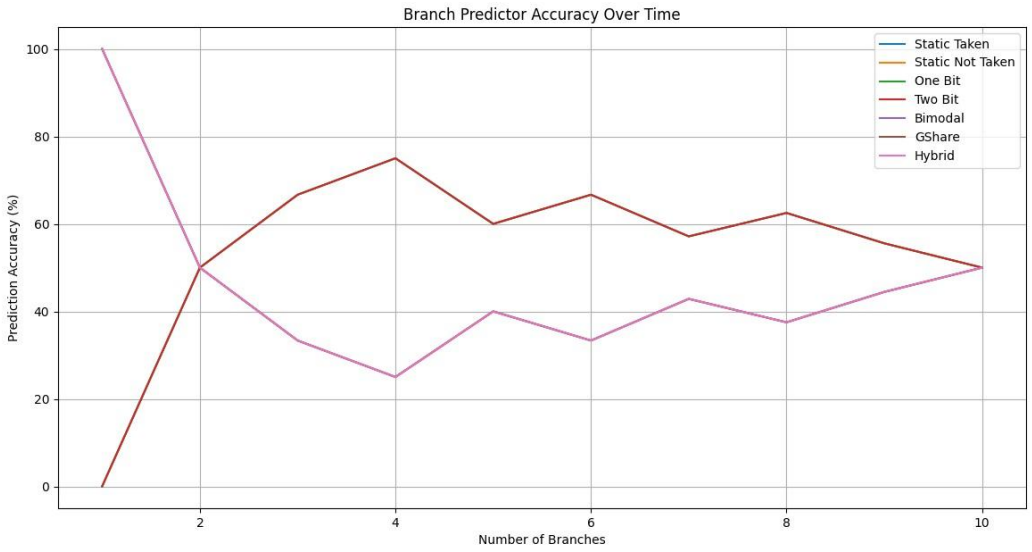
These results make sense because in this custom trace checks with each address that is unique and occurs only at one point in time, so the predictor responds with a not taken/weakly not taken for every prediction. In the case of addresses with outcome 1, these will result in incorrect prediction. This works correctly for addresses with outcome 0. The result of this is, since there is an equal distribution of the 1s and 0s, I've already guaranteed 50% accuracy.

Table 3: Overall Accuracy of Custom Trace

Predictor	Total Branches Processed	Overall Accuracy (%)
Static Taken	10	50
Static Not Taken	10	50

Predictor	Total Branches Processed	Overall Accuracy (%)
One Bit	10	50
Two Bit	10	50
Bimodal	10	50
GShare	10	50
Hybrid	10	50

A custom trace plot was also generated to visualize how it goes to 50% accuracy after the last (10th iteration).:

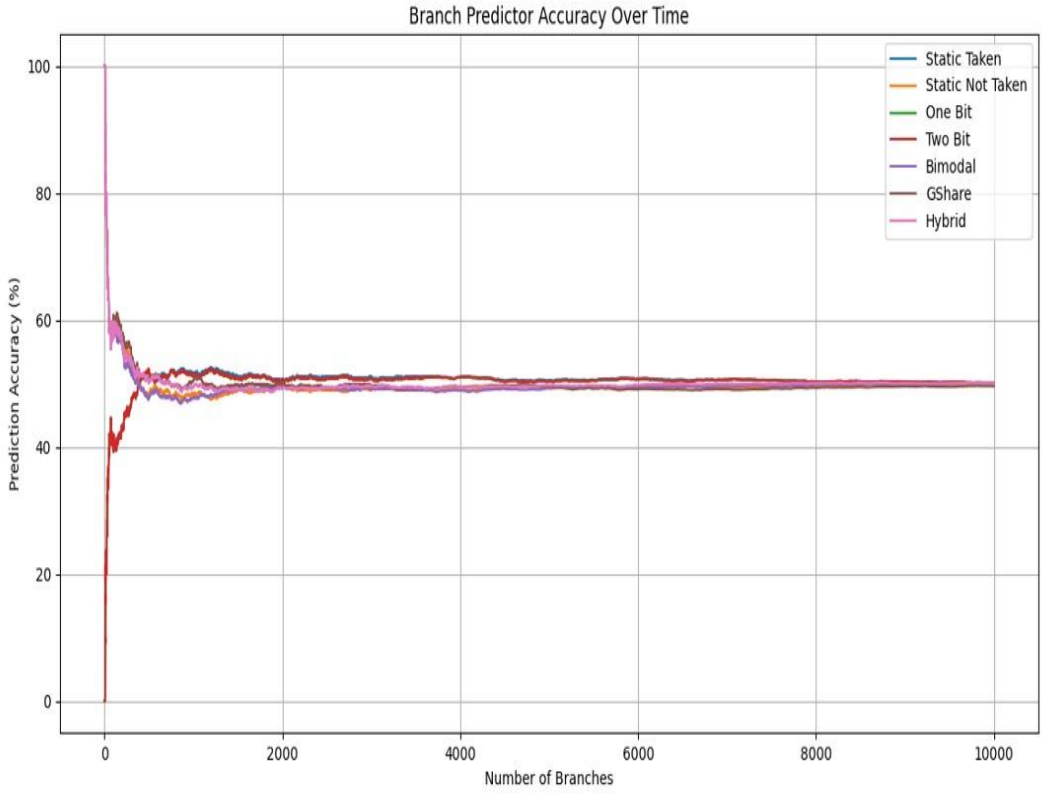


- These results are expected, as all other predictors in this test case yield an accuracy of 50%. Equally, the predictions are split between the Static Taken and Static Not Taken predictors and thus have identical accuracy.
- The One Bit and Two-Bit predictors first lag behind but eventually catch up and achieve an accuracy of 50 percent. This means they didn't make much of a gain from their statebased mechanisms using the small sample size of 10 which does make sense.

- Last, our Bimodal predictor, using address specific history, also achieves 50% accuracy. Given its use of the last outcome per address, this strategy does not improve over simpler strategies, as this dataset is structured.
- In this case, the GShare predictor which takes global history into account does not outperform the others. The limited data hinders the global correlation mechanism's sizeable impact, keeping its accuracy at 50%.
- The Hybrid predictor joins GShare and Bimodal however it does not deliver noticeable improvement. However, lack of a large enough sample size drives down the effectiveness of the choice table such that its overall accuracy is 50%.

It should be noted that the purpose of this custom trace is simply to analyze what would happen to the static predictors if handed a very small, handpicked dataset. This shows that they both work according to plan!

3. Plots that show the branch predictor accuracy over time. The xaxis should be the Number of Branches and the y-axis should be the Prediction Accuracy (%):



In the above plot of the prediction accuracy generated during the simulation. It shows each predictor's prediction accuracy over time. Prediction is given as percentage of accuracy and is plotted on the y-axis, and the number of branches processed on the x-axis. Visually, the plot compares adaptation in accuracy of each predictor to time as more branches are processed.

4. Elaborate on the results of the predictors and why some predictors performed better than others:

The Bimodal Predictor came out on top with a cumulative accuracy of 50.12%, showing its ability to adapt well to branch behaviors. Its use of a two-bit counter helps stabilize predictions and reduce errors caused by noisy patterns. However, it did run into issues with aliasing, where overlapping branch addresses in its table created conflicts, hurting its accuracy on workloads with mixed local patterns.

Right behind it was the Two-Bit Predictor, with an accuracy of 50.1%. This predictor uses extra state information, which helps it handle alternating and streaky patterns better than simpler models. Its stabilizing mechanism prevents unnecessary flips, but it can struggle when patterns alternate too frequently, especially if it starts in a weak state. This can lead to less-than-ideal performance in situations that demand rapid adjustments.

The One-Bit Predictor scored 50.05%, beating the static predictors but falling short compared to the more advanced designs. It works well with repetitive patterns because it quickly adjusts to outcomes. However, its single-bit state makes it less effective for alternating patterns, as it lacks the stabilizing features of the Two-Bit and Bimodal predictors.

Static predictors had the lowest accuracies, with Static Taken at 50.04% and Static Not Taken at 49.96%, mainly because they don’t adapt to changes at all. Static Taken performed fine when most branches were taken, and Static Not Taken did well with consistently untaken branches. But they both fell apart on mixed or alternating traces, making them unreliable for more realistic scenarios.

The GShare Predictor, with 50% accuracy, uses global history to detect patterns across correlated branches. While it shines on datasets with strong global patterns, it struggles with local

ones or when its history size isn't set up properly. On top of that, aliasing in its global history table caused accuracy to drop on traces with overlapping branches.

The Hybrid Predictor, which combines GShare and Bimodal, didn't live up to its potential. With an accuracy of 49.9%, it struggled to effectively balance the strengths of its components. Its performance highlights the need for careful tuning, as combining global and local strategies doesn't always guarantee better results—especially when workloads don't clearly favor one pattern type.

Overall, the results show that while advanced predictors like Bimodal and Two-Bit perform better than static models, they're still not perfect. More complex designs like GShare and Hybrid have a lot of promise but require better tuning and optimization to consistently outperform simpler approaches. Aliasing and configuration issues remain major hurdles for these predictors.

References and Supporting Images for Tables and Code (Recommended to use MS Word Tables by TA):

For Part 2)

Tables 1 and 2:

```
Processing Branch Address: 41192
+------------------+----------------------+--------------------------+
| Predictor        |   Branches Processed |   Cumulative Accuracy (%) |
+==================+======================+==========================+
| Static Taken     |                10000 |                    50.04 |
+------------------+----------------------+--------------------------+
| Static Not Taken |                10000 |                    49.96 |
+------------------+----------------------+--------------------------+
| One Bit          |                10000 |                    50.05 |
+------------------+----------------------+--------------------------+
| Two Bit          |                10000 |                    50.1  |
+------------------+----------------------+--------------------------+
| Bimodal          |                10000 |                    50.12 |
+------------------+----------------------+--------------------------+
| GShare           |                10000 |                    49.56 |
+------------------+----------------------+--------------------------+
| Hybrid           |                10000 |                    49.99 |
+------------------+----------------------+--------------------------+
+------------------+---------------------------+-----------------------+
| Predictor        |   Total Branches Processed |   Overall Accuracy (%) |
+==================+===========================+=======================+
| Static Taken     |                     10000 |                 50.04 |
+------------------+---------------------------+-----------------------+
| Static Not Taken |                     10000 |                 49.96 |
+------------------+---------------------------+-----------------------+
| One Bit          |                     10000 |                 50.05 |
+------------------+---------------------------+-----------------------+
| Two Bit          |                     10000 |                 50.1  |
+------------------+---------------------------+-----------------------+
| Bimodal          |                     10000 |                 50.12 |
+------------------+---------------------------+-----------------------+
| GShare           |                     10000 |                 49.56 |
+------------------+---------------------------+-----------------------+
| Hybrid           |                     10000 |                 49.99 |
+------------------+---------------------------+-----------------------+
```

Custom Trace Tables 3 and 4:

```
Processing Branch Address: 49480
+------------------+-----------------------+----------------------------+
| Predictor        |   Branches Processed  |   Cumulative Accuracy (%)  |
+==================+=======================+============================+
| Static Taken     |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
| Static Not Taken |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
| One Bit          |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
| Two Bit          |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
| Bimodal          |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
| GShare           |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
| Hybrid           |                    10 |                         50 |
+------------------+-----------------------+----------------------------+
```

```
+------------------+-----------------------------+-------------------------+
| Predictor        |   Total Branches Processed  |   Overall Accuracy (%)  |
+==================+=============================+=========================+
| Static Taken     |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
| Static Not Taken |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
| One Bit          |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
| Two Bit          |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
| Bimodal          |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
| GShare           |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
| Hybrid           |                          10 |                      50 |
+------------------+-----------------------------+-------------------------+
```