

# Assignment 1b

## Branch Prediction in GEM-5

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## Problem Statement:

- **Implementation of Blocked Matrix Multiplication:** Perform blocked matrix multiplication on relatively small input sizes.
- **Simulation Using gem5:** Run the implemented program on the gem5 simulator, varying the following hardware parameters:
  - **CPU Models:** Test the program across different CPU models available in gem5.
  - **Branch Prediction Methodologies:** Evaluate performance by varying different available branch predictions methods as mentioned in
    - > `gem5/src/cpu/pred/BranchPredictor.py`.
  - **CPU Clock Frequency:** (fixed) 2GHz.
  - **Memory Configurations:** (fixed) DDR4\_2400\_8x8.
- **Performance Analysis:** Describe and analyze the branch prediction statistics (e.g., Branch Predicted or not, if yes, taken or not) resulting from the different CPU models & branch prediction methodologies.

## Simulation Parameters:

(Matrix Used: 30x30, with a block\_size of 3x3)

- **CPU Models:** DerivO3CPU, TimingSimpleCPU
- **Branch Prediction Methodologies:** BiModeBP, LocalBP, TAGE, TournamentBP

## Evaluation:

- *Config.ini file for BiMode Branch Predictor :*

```
[system.cpu.branchPred]
type=BiModeBP
children=btb indirectBranchPred ras
btb=system.cpu.branchPred.btb
choiceCtrBits=2
choicePredictorSize=8192
eventq_index=0
globalCtrBits=2
globalPredictorSize=8192
indirectBranchPred=system.cpu.branchPred.indirectBranchPred
instShiftAmt=2
numThreads=1
ras=system.cpu.branchPred.ras
requiresBTBHit=false
```

- *Config.ini file for Local Branch Predictor :*

```
[system.cpu.branchPred]
type=LocalBP
children=btb indirectBranchPred ras
btb=system.cpu.branchPred.btb
eventq_index=0
indirectBranchPred=system.cpu.branchPred.indirectBranchPred
instShiftAmt=2
localCtrBits=2
localPredictorSize=2048
numThreads=1
ras=system.cpu.branchPred.ras
requiresBTBHit=false
```

- **Config.ini file for TAGE Branch Predictor :**

```
[system.cpu.branchPred]
type=TAGE
children=btb indirectBranchPred ras tage
btb=system.cpu.branchPred.btb
eventq_index=0
indirectBranchPred=system.cpu.branchPred.indirectBranchPred
instShiftAmt=2
numThreads=1
ras=system.cpu.branchPred.ras
requiresBTBHit=false
tage=system.cpu.branchPred.tage
```

- **Config.ini file for Tournament Branch Predictor :**

```
[system.cpu.branchPred]
type=TournamentBP
children=btb indirectBranchPred ras
btb=system.cpu.branchPred.btb
choiceCtrBits=2
choicePredictorSize=8192
eventq_index=0
globalCtrBits=2
globalPredictorSize=8192
indirectBranchPred=system.cpu.branchPred.indirectBranchPred
instShiftAmt=2
localCtrBits=2
localHistoryTableSize=2048
localPredictorSize=2048
numThreads=1
ras=system.cpu.branchPred.ras
requiresBTBHit=false
```

- **Simulation results :**

Following parameters were acquired on running the simulation on both DerivO3CPU & TimingSimpleCPU using various branch prediction methods:

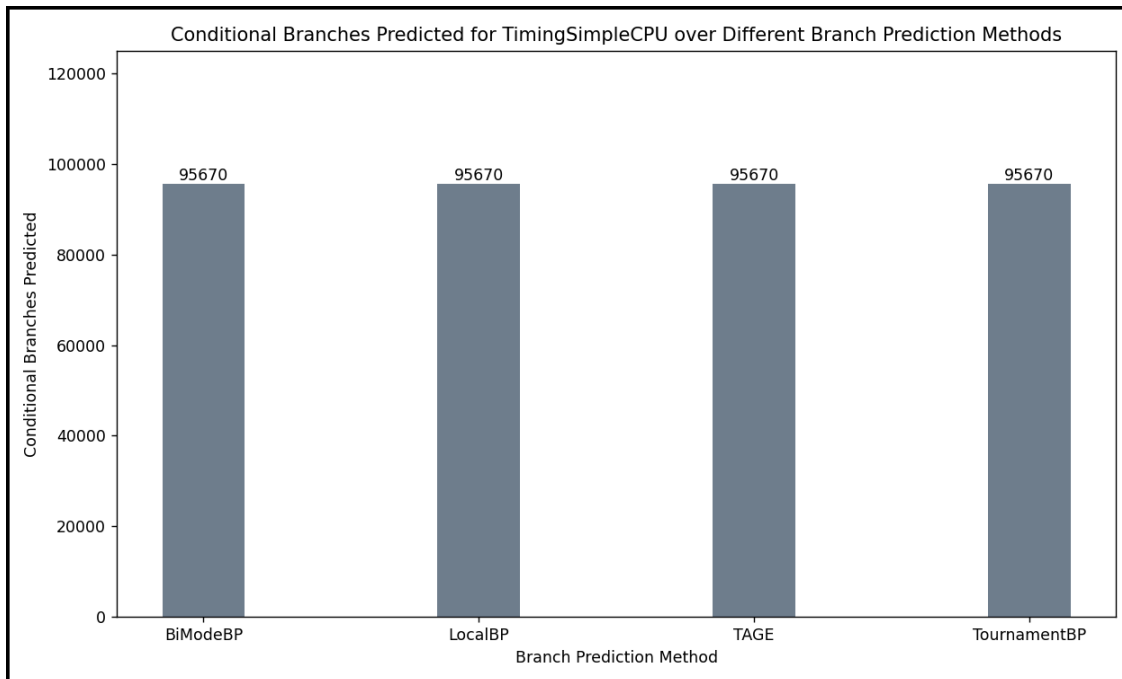
Configuration	simSeconds(ms)	cpi	condPredicted	condPredictedTaken	condIncorrect	TakenMispredicted	NotTakenMispredicted
DerivO3CPU_BiModeBP	8.161	9.36934	107344	58278	5568	252	5316
DerivO3CPU_TournamentBP	7.406	8.502244	97077	56315	945	83	862
DerivO3CPU_LocalBP	9.819	11.272931	110269	56168	15358	1487	13871
DerivO3CPU_TAGE	7.43	8.530268	97527	56246	1034	173	861
TimingSimpleCPU_BiModeBP	131.132	150.542306	95670	50111	6262	142	6120
TimingSimpleCPU_TournamentBP	131.132	150.542306	95670	55597	759	80	679
TimingSimpleCPU_LocalBP	131.132	150.542306	95670	41498	14989	177	14812
TimingSimpleCPU_TAGE	131.132	150.542306	95670	54895	1532	166	1366

Configuration	BTBLookups	BTBUpdates	BTBHits	BTBHitRatio
DerivO3CPU_BiModeBP	124887	5195	121997	0.976859
DerivO3CPU_TournamentBP	111378	756	108742	0.976333
DerivO3CPU_LocalBP	111378	756	108742	0.976333
DerivO3CPU_TAGE	124887	5195	121997	0.976859
TimingSimpleCPU_BiModeBP	109387	595	107987	0.987201
TimingSimpleCPU_TournamentBP	109387	595	107987	0.987201
TimingSimpleCPU_LocalBP	109387	14728	107987	0.987201
TimingSimpleCPU_TAGE	109387	1282	107987	0.987201

- ***TimingSimpleCPU*** (simplified, in-order non- pipelined CPU model) :

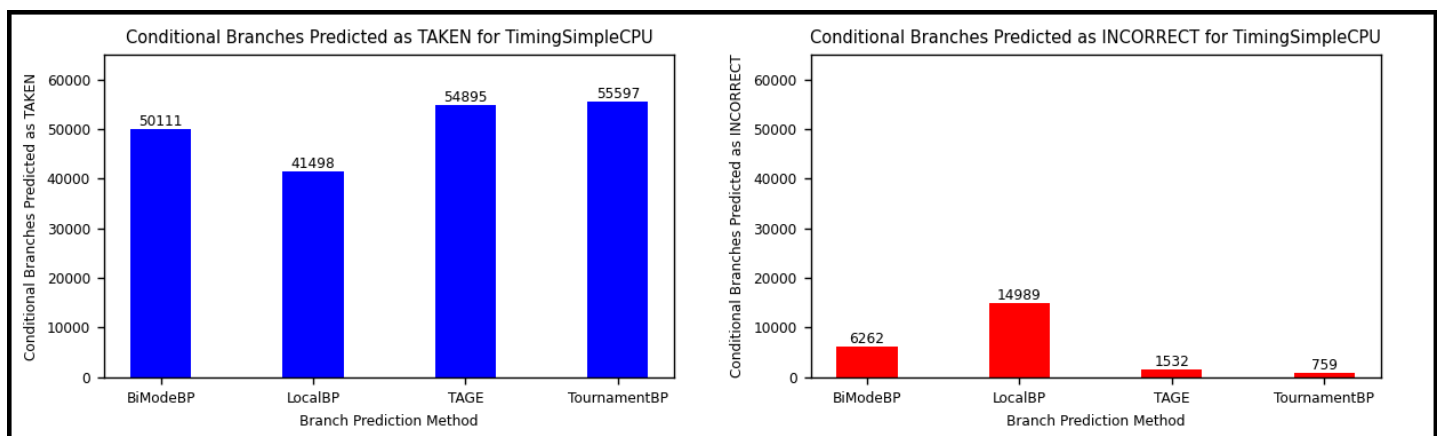
**Simulation Time** : Almost same (131ms) for various Branch methods.

### **Number of Branches Predicted :**



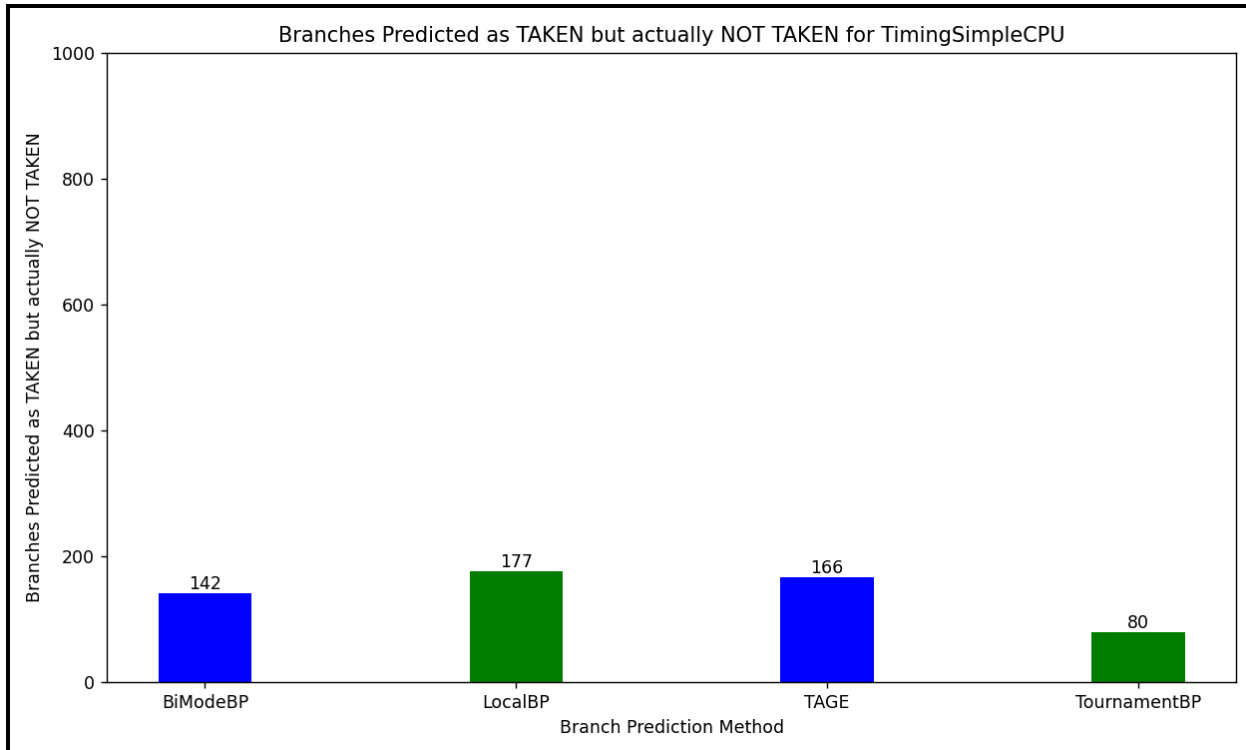
### **Number of Branches : Predicted as TAKEN**

**INCORRECT**

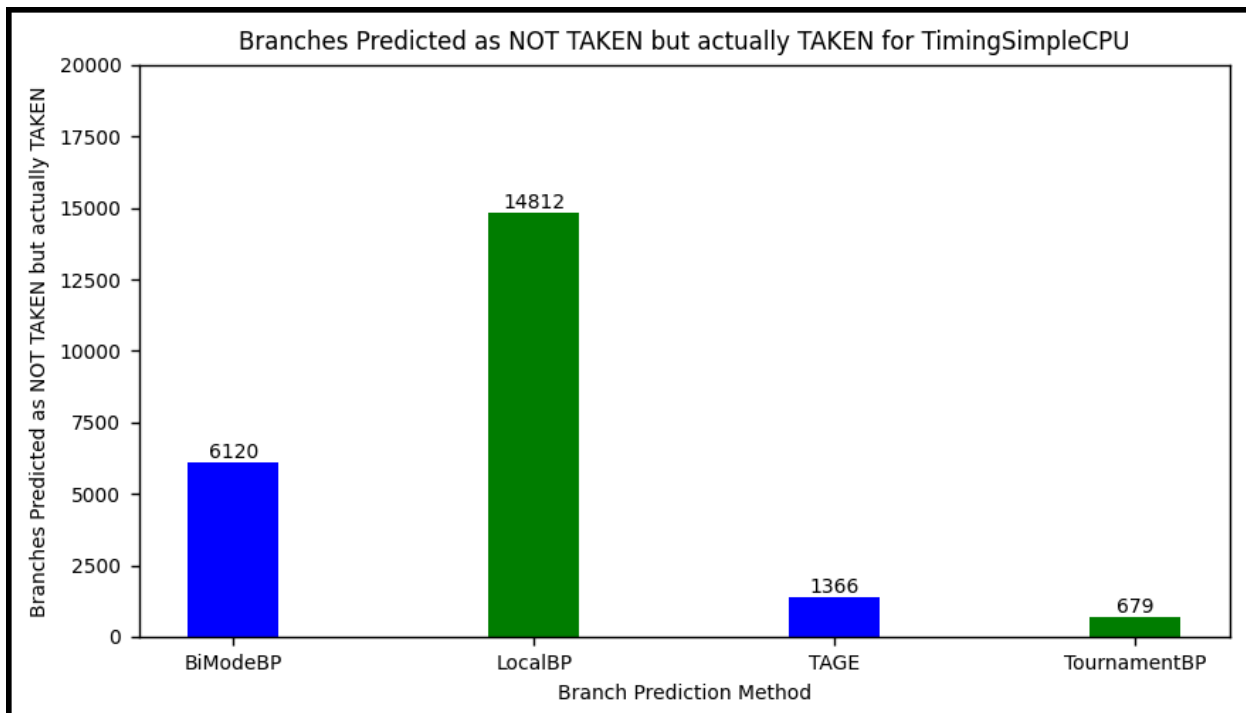


## **Mispredictions :**

### ***Number of Branches Predicted as TAKEN but actually NOT TAKEN:***



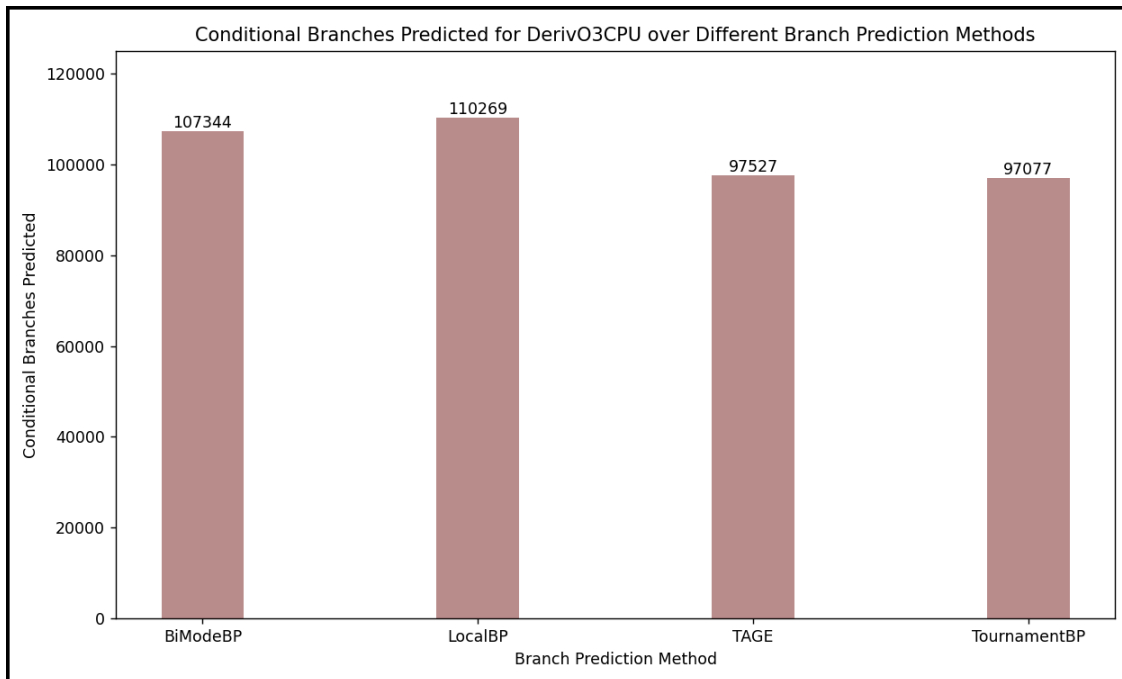
### ***Number of Branches Predicted as NOT TAKEN but actually TAKEN:***



- **DerivO3CPU** (detailed, out-of-order pipelined CPU model) :

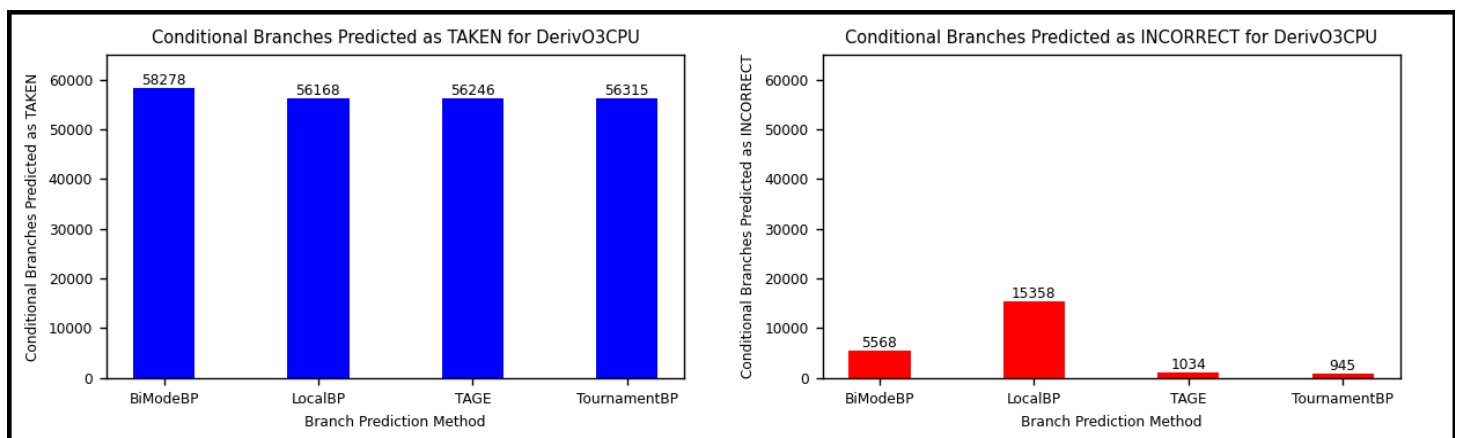
**Simulation Time** : Varied slightly (7-10ms) for various Branch methods.

### **Number of Branches Predicted :**



### **Number of Branches : Predicted as TAKEN**

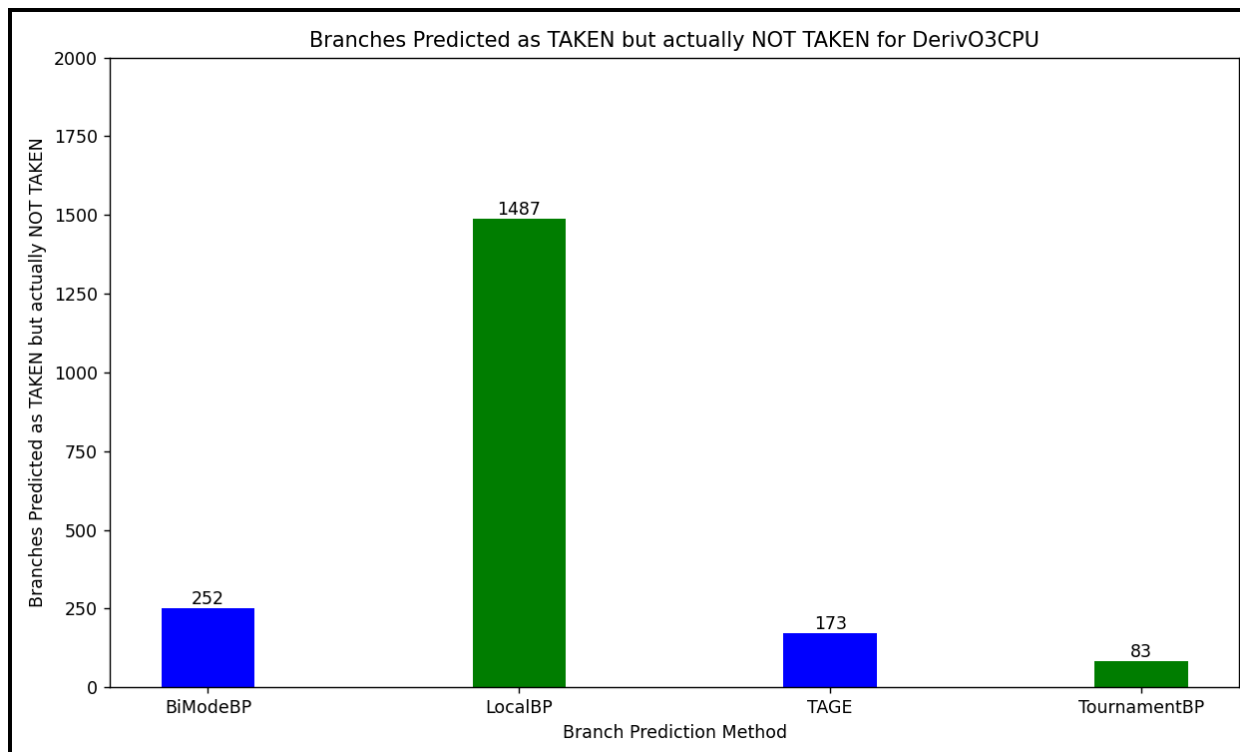
**INCORRECT**



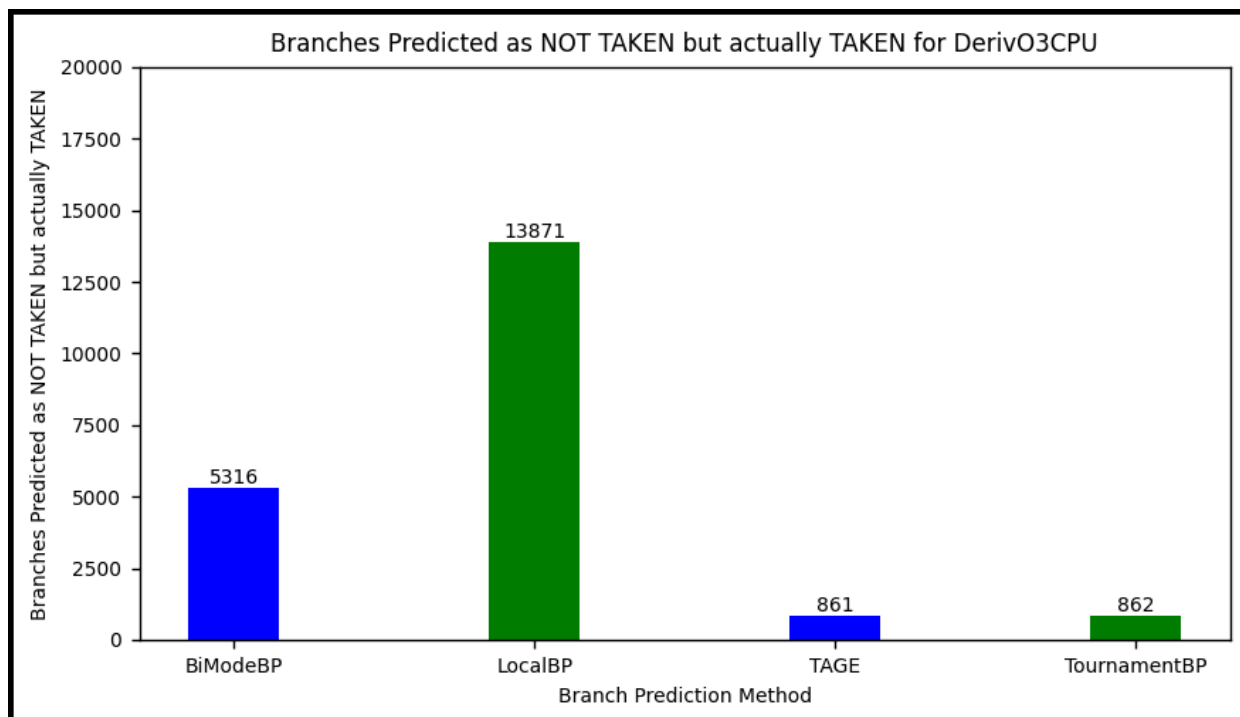


## **Mispredictions :**

### ***Number of Branches Predicted as TAKEN but actually NOT TAKEN:***



### ***Number of Branches Predicted as NOT TAKEN but actually TAKEN:***



- **Result:**

- **DerivO3CPU BiModeBP** predicts the highest number of branches (107,344), while all other predictors have slightly lower values. BiModeBP may predict more branches as they handle bimodal branches more efficiently, while for **TimingSimpleCPU**, has consistent lower values across predictors.
- **DerivO3CPU BiModeBP** displayed the highest number of incorrect predictions (5,568), whereas **TimingSimpleCPU TournamentBP** has one of the lowest (759). More incorrect predictions for BiModeBP could indicate that, while it predicts a higher number of branches, it sacrifices accuracy. Whereas, TournamentBP leads to fewer incorrect predictions.
- **LocalBP** performs poorly in identifying branch behavior across both CPU models. In contrast, **TournamentBP** is better suited for both simple and complex CPUs, as it offers greater accuracy in predicting both TAKEN and NOT TAKEN branches.
- **Branch Target Buffer(BTB) stats** indicate *high hit ratios* and similar BTB *performance* across predictors, they don't offer much differentiation between predictor suitability.

For **TimingSimpleCPU**, TournamentBP emerges as the most suitable branch predictor due to its low number of incorrect predictions and TAKEN mispredictions.

For **DerivO3CPU**, BiModeBP predicts the highest number of branches but at the cost of higher mispredictions.