champsim

ES215 Project Report

> **Title**: Analysing Branch Predictors' Performance on ChampSim

Week 1

Task 1

> Log

1. We cloned ChampSim from GitHub, on three different environments.
    i. Windows Subsystem for Linux (WSL) Ubuntu 18.04
    ii. Ubuntu 18.04 on Virtual Box
    iii. !Pop_OS (Linux Distribution Based on Ubuntu)
2. Installed essential dependencies.
3. Ran the following script. Can be downloaded here.

> Script

```
cd ..

mkdir -p logs

echo  'TASK 1\nStart Time: ' >> ./logs/task-1.txt
echo  'TASK 1 ERRORS/WARNINGS\n' >> ./logs/task-1-err.txt

exec 1>> ./logs/task-1.txt
exec 2>> ./logs/task-1-err.txt

./build_champsim.sh bimodal no no no no lru 1    # single core build
echo '\n\nBuild Completed. Running the 1 core build.\n\n'
./run_champsim.sh bimodal-no-no-no-no-lru-1core 1 10 400.perlbench-41B.champsimtrace.xz # single co
```

```
echo '\n\nTask 1 Part 1 completed!\n\n'


./build_champsim.sh bimodal no no no no lru 4    # four core build
echo '\n\nBuild Completed. Running the 4 core build.\n\n'
./run_4core.sh bimodal-no-no-no-no-lru-4core 1 10 0 400.perlbench-41B.champsimtrace.xz 454.calculix
echo '\n\nTask 1 Part 2 completed!\n\n'

echo '\n\nTask 1 completed! :)\n\n'

exit
```

The script ran successfully. Details of the simulations are given below.

Task 1.1

> Built a CPU with the following **parameters** -

```
Branch Predictor: Bimodal
Warmup Instructions: 1 million
Simulation Instructions: 10 million
Number of CPUs: 1
Prefetchers: None
Off-chip DRAM Size: 4096 MB
```

Results from Task 1.1

```
Heartbeat instructions: 10000003
cycles: 17581198
heartbeat IPC: 0.56879
cumulative IPC: 0.525805
Simulation time: 21 sec

Finished instructions: 10000000
cycles: 18628767
cumulative IPC: 0.5368 04
Simulation time: 23 sec

Branch Prediction Accuracy: 95.4821%
MPKI: 9.4899
Average ROB Occupancy atMispredict: 51.163
```

Task 1.2

> Built a system of 4 CPUs with the following ***common*** **parameters** -

```
Branch Predictor: Bimodal
Warmup Instructions: 1 mil
Simulation Instructions: 10 mil
Prefetchers: None
Off-chip DRAM Size: 4096 MB
```

Results from Task 1.2

Traces Used	CPU `i`
400.perlbench	CPU `0`
454.calculix	CPU `1`
603.bwaves	CPU `2`
649.fotonik3d	CPU `3`

Parameters	CPU 0	CPU 1	CPU 2	CPU 3
CPU Comp. Time (in sec)	138	68	67	79
Cumulative IPC	0.536671	1.18435	1.19862	0.990379
Branch Pred. Acc. (in %)	95.4821	72.2496	88.7848	96.1452
MPKI	9.4899	24.8147	14.9489	9.09982
ROB Occupancy at Mispredict	51.1779	28.1235	20.2697	48.011

Task 2

> Log

1. Built **4** single core CPUs with the following branch predictors -
    - Bimodal
    - Gshare
    - Hashed Perceptron
    - Perceptron
2. Ran the following four traces on each of the builds -
    - 454.calculix-104B.champsimtrace.xz
    - 603.bwaves_s-5359B.champsimtrace.xz
    - 649.fotonik3d_s-1B.champsimtrace.xz
    - 654.roms_s-1021B.champsimtrace.xz

3. So, a total of 16 simulations were run. Automated the processs by writing (and running) this `Bash` script.

4. Common Parameters for all simulations :

```
Warmup Instructions: 1 million
Simulation Instructions: 10 million
Number of CPUs: 1
Off-chip DRAM Size: 4096 MB
```

Insights

> ### Do different benchmark traces have different prediction rates?

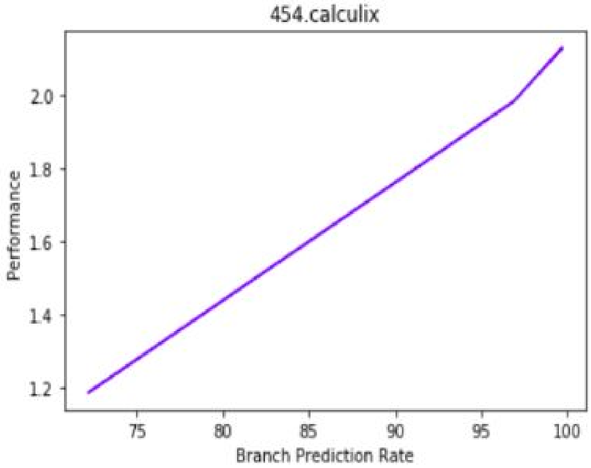
Below table shows Prediction rates of four different branch predictors for four different benchmark traces.

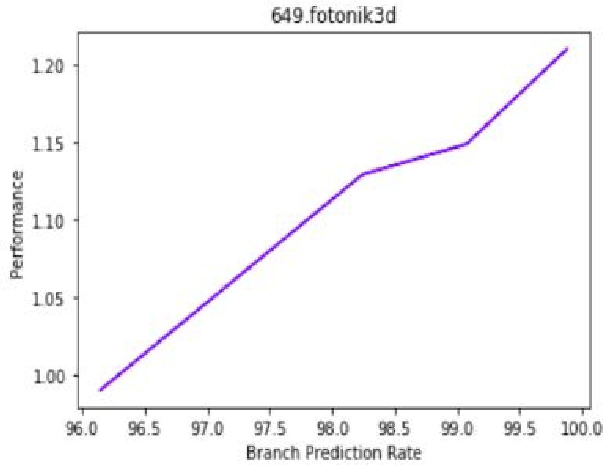
Traces	Bimodal	Gshare	Hashed Perceptron	Perceptron
454.calculix	72.2378	96.8821	99.6659	96.9556
603.bwaves	87.5014	93.5709	99.8845	91.48
649.fotonik3d	96.145	98.2442	99.8778	99.0743
654.roms	81.4508	97.92	99.8879	98.1034

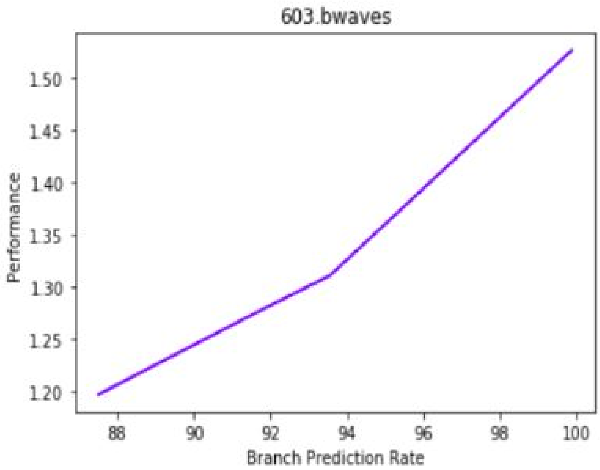
Inference: Different benchmark traces have different predictions rates. Here, `649.fotonik3d` has the best prediction rate among all the benchmark traces for any given branch predictor. From this data, it appears as if the trace `649.fotonik3d` has **instructions that follow a defined pattern**, and thus all branch predictors work well for it. Conversely, `454.calculix` shows the widest range in prediction rates; apparenty implying that it's instruction set doesn't conform to a pattern as strongly as the other traces.

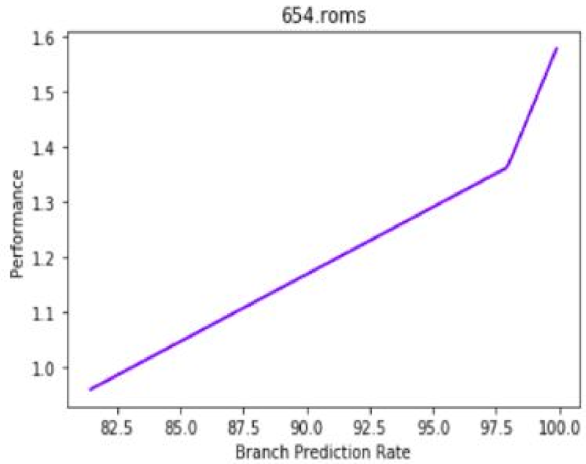
> ### Relating Branch Prediction Rate with Performance

Each of the graph below, depicts how performance changes for different Branch Predictors (and hence, different `BP Rates`) with respect to a given trace. We acknowledge that for each of these plots are composed for four data-points. ***Assuming***, that these graphs extrapolate for other prediction rates, there seems to be a **direct relation** between the two quantities. In essence, **if the a Branch Predictor offers a better prediction rate for a trace, then it is likely to perform better (`higher IPC`).**









Here, `Performance` is measureed in `Instructions Per Cycle` (aka `IPC`).

> ## Relating Branch Prediction Rates to Design of Branch Predictors

Traces	Bimodal	Gshare	Hashed Perceptron	Perceptron
454.calculix	72.2378	96.8821	99.6659	96.9556
603.bwaves	87.5014	93.5709	99.8845	91.48
649.fotonik3d	96.145	98.2442	99.8778	99.0743
654.roms	81.4508	97.92	99.8879	98.1034

Coloumn-wise analysis of the above table indicates that different predictors have different prediction rates. Here, `hashed_perceptron` is most efficient, followed by `perceptron`, `gshare` and `bimodal`.

> **Bimodal branch predictor :**
>
> - The bimodal branch predictor uses 2-bit saturated counters. This counters helps to keep the track of the result(branch taken or not taken) in the previous encounter of this branch instruction.
> - Data for every branch instruction's 2 bit Saturated counter is stored in a Branch Predictor table. This table updates after any counter of any branch instruction changes.

> - Every time if branch is taken, you increment the value of saturated counter unless it is max or 11.
> - Every time if branch NOT taken, you decrement the value of saturated counter unless it is minimum or 00.
> - So, next time you encounter this particular branch instruction, it see the value of the saturated counter and act accordingly.

> **Gshare:**
>
> - Gshare uses the same history table or branch prediction table but also uses the Program Counter to check if the branch is to be taken or not.
> - It XORs value of saturated counter of instruction from the branch prediction table with PC (program counter). This provides it a more performance advantage in terms of prediction accuracy.
> - It allows better utilization of PHT. But increases access latency.

> **Perceptron Branch Predictors:**
>
> - In this branch predictor a Perceptron is used to predict whether the predictor will predict a branch to be taken or not. Previous branch prediction history (local or global) is used as input to the perceptron and decision boundary between data is drawn.
> - Here, output is predicted as -1 if branch is not taken and +1 if it is taken. The performance of prediction depends on the nature of the classification boundary i.e. whether it is a line or a curve. Perceptron branch predictor works better if the data is linearly separable. Although modern ANN can predict the more complicated boundaries but a lot more expensive.
> - Perceptron branch predictors perform very well in most of the predictions with low branch misprediction.

Parameter	454.calculix	603.bwaves	649.fotonik3d	654.roms
Accuracy	96.9556	91.48	99.0743	98.1034
Misprediction per 1000 instructions	2.7431	12.2815	2.2011	3.0796

> **For detailed data of performed Tasks, visit this sheet.**