CS422: Computer Architecture

Homework 2

Implementation Details

Part A code is contained in `predictor.cpp` and `predictor.h`. All predictors are derived from the base class `Predictor` and the actual prediction logic is implemented in an overloaded `operator+`. SAg, GAg and gshare results are passed to the hybrid predictors as a `std::optional` in the `data_t` struct. To reconfigure the sizes of the tables and/or the counters, relevant constants in `predictor.h` should be modified.

Part B code is contained in `btb.cpp`, `hashbtb.cpp`, `btb.h` and `hashbtb.h`. The cache is filled by calling `btb_fill`, and LRU replacement is used. LRU is tracked using a timer, and the entry with the lowest value is the LRU entry.

The final results are reported on a server with 16 threads, and 16 GB RAM. The processor used is - 11th Gen Intel(R) Core(TM) i7-11800H @ 2.30GHz

All the fractions have been listed as percentages.

Results Explanation - Part A

We will have a brief look at the various predictors, starting from worst to best.

The overall worst is of course FNBT, as it does not really learn anything - it can only be successful in certain specific scenarios. One would expect the majority of branches in a program to be from loops, and if the loops have a large iterations/exits ratio and the conditional branch is backward FNBT can work decently well. For eg., the backward misprediction rate for FNBT + 456.hmmer is <1% despite a significant number of backward branches. Obviously generating such code is a huge constraint and is generally not feasible from the compiler's standpoint.

The next worst predictors are GAg, gshare and the bimodal predictor. Which one works better depends on the specific benchmark. It is clear why bimodal is not such a good predictor, as it can only predict branches which have a high degree of certainty towards a certain outcome. Even then, for example in a loop which exits after 5 iterations, the bimodal predictor will have a misprediction every 5'th time, whereas any history-based predictor will not.

Obviously using global history will help certain kind of branches, whereas there will be branches which will highly correlate with their local history instead of the global one. The usual trend of misprediction rates is `GAg > gshare >> SAg`. From this, we hypothesize that most branches correlate more with their local histories than global ones. GAg and gshare have similar misprediction rates - however as gshare avoids aliasing, i.e because of the XOR it can differentiate b/w branches with the same history, it is slightly better than GAg on average.

SAg maintains the local history of branches in a table which allows for an accurate record of the local histories with very low aliasing. This combined with our hypothesis explains why SAg is clearly better than GAg and gshare.

The hybrid predictors are the most accurate, as one would expect. The majority predictor is the worst amongst the three, and is sometimes even worse than SAg - this is expected as gshare and GAg will produce somewhat similar results. What was surprising to us is that the majority predictor still works fairly well, which would mean that gshare and GAg mispredictions are often on different kind of branches.

As an example, we can look at 403.gcc. The misprediction rates are `SAg = 5%, GAg = 15%, gshare = 9%, majority = 5.4%`. This is an extreme example, but nevertheless we can see that gshare performs much better than GAg, which shows that aliasing is a big issue for certain applications, and that also explains why a simple majority works pretty well despite GAg and gshare having the same fundamental idea.

The hybrid b/w SAg and GAg and the tournament predictor have similar results. For the former, we update the meta-table only when SAg and GAg have different outcomes. This seems the obvious way to us.

However, upon doing this with the tournament predictor, i.e updating all 3 meta-tables simulatenously but updating a table only when the two predictors it is comparing have unequal predictions, we achieved results better than the given reference output. To match with the reference output, we have changed our implementation to update all 3 tables irrespective of whether the predictors a meta-table is comparing have equal results.

This has given slightly worse results. As the logic b/w the SAG + GAg hybrid and the tournament predictor is now fundamentally different, there is not much point trying to compare their mostly similar results. They both work better than a simple majority as they are able to learn the most suitable predictor for every branch.

Results Explanation - Part B

From the results, it is evident that the BTB indexed solely with the PC of the instruction has a lower miss rate, but the BTB indexed with the hash of the PC and the GHR has a lower misprediction rate in general.

Indexing the BTB with the PC of the instruction leads to a lower miss rate, since every time the program looks up the instruction, it is found in the same place. However, this leads to a higher misprediction rate, since the BTB is not really adapting to the dynamic conditions dictated by the program.

Indexing the BTB with the hash of the PC and the GHR of the last n conditional branches leads to a higher miss rate, since every time an instruction is encountered, it is possible that the index we are looking for it in, has not been touched. This does contribute to a lower misprediction rate, since the BTB is learning from the program, and adapting its indexing accordingly.

The best example for demonstrating this is `gcc`, where the miss rate for the second BTB is almost `400` times the miss rate for the normal BTB, but the misprediction rate is half. Given that the miss rate for `gcc` is extremely low (0.0001%) for the normal BTB, but the misprediction rate is 70%, the penalty in the miss rate for the second BTB is insignificant compared to the improvement in prediction.

Benchmark Results

400.perlbench diffmail.pl

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	130101783	41.4324%	37.7532%	56.2276%
Bimodal	130101783	9.43105%	9.7841%	8.01129%
SAg	130101783	3.62852%	3.70322%	3.32812%
GAg	130101783	11.6579%	12.324%	8.97914%
gshare	130101783	10.0557%	10.1364%	9.73105%
Hybrid-1	130101783	3.09021%	3.17035%	2.7679%
Hybrid-2 Majority	130101783	4.9575%	5.01487%	4.72681%
Hybrid-2 Tournament	130101783	3.9031%	4.12987%	2.99119%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	28134124	0.01209%	34.67776%
BTB indexed with hash of PC and global history	28134124	1.78012%	10.22728%

401.bzip2 input.source

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	129923039	46.8918%	30.9891%	61.9444%
Bimodal	129923039	9.99838%	10.7903%	9.24879%
SAg	129923039	10.1409%	11.4241%	8.92617%
GAg	129923039	12.5105%	14.7517%	10.389%
gshare	129923039	11.3094%	12.1151%	10.5467%
Hybrid-1	129923039	9.5824%	10.8428%	8.38938%
Hybrid-2 Majority	129923039	9.3016%	10.201%	8.45027%
Hybrid-2 Tournament	129923039	9.5726%	10.6397%	8.56253%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	791909	0.00745%	48.29393%
BTB indexed with hash of PC and global history	791909	0.02702%	47.52377%

403.gcc cp-decl.i

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	145814336	36.5858%	31.8015%	54.1155%
Bimodal	145814336	12.9411%	14.7189%	6.4272%

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
SAg	145814336	5.09652%	5.36705%	4.10526%
GAg	145814336	15.4023%	16.1536%	12.6497%
gshare	145814336	9.73444%	9.13051%	11.9473%
Hybrid-1	145814336	4.19446%	4.50981%	3.03896%
Hybrid-2 Majority	145814336	5.39209%	5.35454%	5.52966%
Hybrid-2 Tournament	145814336	4.71379%	4.79988%	4.39832%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	34737233	0.000106%	70.62674%
BTB indexed with hash of PC and global history	34737233	0.045139%	31.76835%

429.mcf

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	172842909	31.9495%	35.7088%	28.1899%
Bimodal	172842909	18.02%	16.2883%	19.7519%
SAg	172842909	13.0502%	15.0982%	11.0021%
GAg	172842909	9.28587%	9.22752%	9.34423%
gshare	172842909	10.2195%	10.3481%	10.0909%
Hybrid-1	172842909	8.7753%	8.94987%	8.60071%
Hybrid-2 Majority	172842909	8.68154%	8.7609%	8.60217%
Hybrid-2 Tournament	172842909	8.88845%	9.08998%	8.68689%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	12556349	0.000072%	0.61349%
BTB indexed with hash of PC and global history	12556349	0.0008362%	0.40991%

450.soplex ref.mps

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	103219361	17.0122%	19.9393%	15.5894%
Bimodal	103219361	4.8278%	0.910829%	6.73185%
SAg	103219361	4.02024%	0.657045%	5.65509%
GAg	103219361	3.81006%	0.849235%	5.24932%
gshare	103219361	3.98045%	1.29791%	5.28444%
Hybrid-1	103219361	3.58499%	0.650398%	5.0115%
Hybrid-2 Majority	103219361	3.79203%	0.819812%	5.23683%
Hybrid-2 Tournament	103219361	3.66753%	0.677946%	5.12078%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	6315969	0.0014883%	0.005351%
BTB indexed with hash of PC and global history	6315969	0.0053990%	0.010465%

456.hmmer nph3.hmm

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	144361424	63.9146%	76.6315%	0.669822%
Bimodal	144361424	8.55505%	10.2041%	0.353847%

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
SAg	144361424	9.12542%	10.8637%	0.480347%
GAg	144361424	11.7689%	13.6194%	2.56574%
gshare	144361424	10.2741%	11.7958%	2.70623%
Hybrid-1	144361424	8.64265%	10.2256%	0.770076%
Hybrid-2 Majority	144361424	8.68884%	10.3102%	0.625552%
Hybrid-2 Tournament	144361424	8.68196%	10.3029%	0.620389%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	201570	0.056556%	6.385375%
BTB indexed with hash of PC and global history	201570	0.4216897%	2.64077%

471.omnetpp

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	117335288	34.1219%	33.7247%	36.1847%
Bimodal	117335288	10.3997%	9.72771%	13.8898%
SAg	117335288	5.003%	4.36208%	8.33151%
GAg	117335288	12.2328%	11.8266%	14.3424%
gshare	117335288	10.8435%	10.3791%	13.2551%
Hybrid-1	117335288	4.11894%	3.584%	6.89712%
Hybrid-2 Majority	117335288	5.48414%	4.76363%	9.22605%
Hybrid-2 Tournament	117335288	5.02242%	4.3817%	8.34993%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	30294701	0.018828%	29.360996%
BTB indexed with hash of PC and global history	30294701	0.878609%	11.637649%

483.xalancbmk

Part A

Predictor	Total Predictions	Total Misprediction	Forward Misprediction	Backward Misprediction
FNBT	181215584	7.80045%	8.80922%	4.91988%
Bimodal	181215584	3.52299%	4.03331%	2.06576%
SAg	181215584	1.85848%	2.10205%	1.16294%
GAg	181215584	4.52388%	5.04071%	3.04806%
gshare	181215584	3.929%	4.28487%	2.91279%
Hybrid-1	181215584	1.40294%	1.53529%	1.025%
Hybrid-2 Majority	181215584	2.12208%	2.29935%	1.61585%
Hybrid-2 Tournament	181215584	1.70337%	1.90671%	1.12271%

Part B

BTB Type	BTB Predictions	BTB Miss Rate	BTB Misprediction
BTB indexed with PC	32447858	2.356661%	27.51067%
BTB indexed with hash of PC and global history	32447858	15.440501%	27.94729%