Lab 2: Dynamic Branch Prediction

Microbenchmark

We compiled the benchmark with gcc mb.c -o mb, with no additional optimization or debug flags. The code uses two branches. B1 implements a six state pattern TTNNTN, via "if ((i % 6) < 2 || (i % 6) == 4)", that fits in a 6 bit history, so after a short warmup it becomes perfectly predictable given our 2level PaP design. B2 uses an 128 entry sequence where every 6 bit history appears twice, once followed by 0 and once by 1. Here `pattern[k % 128]` simply walks a fixed 0 or 1 sequence in a loop so the branch is taken when the array entry is 1 and not taken when it is 0, and the same PHT entry for a given 6 bit history sees alternating outcomes, yielding about 50 percent accuracy. We validated this by running the microbenchmark twice, first with B2 at 50k iterations and then at 30k iterations, and observed that total mispredictions decreased by a roughly constant amount proportional to the change in B2 iterations (Appendix A).

Summary of Prediction Accuracy Across Benchmarks

The table below contains the total mispredictions and MPKI across eight benchmarks for 2-bit Saturating Counter, Two-Level (PaP), and Open-Ended predictors.

	2bitsat		2level		openend	
	Total Mispredictions	MPKI	Total Mispredictions	MPKI	Total Mispredictions	MPKI
aster	3695722	24.638	1785464	11.903	876899	5.846
bwaves	1182389	7.883	1071909	7.146	847567	5.650
bzip2	1224967	8.166	1297677	8.651	1241999	8.280
gcc	3171856	21.146	2223671	14.824	833907	5.559
gromacs	1353156	9.021	1122586	7.484	823741	5.492
hmmer	2034849	13.566	2230774	14.872	1790554	11.937
mcf	4945398	32.969	2024172	13.494	1560550	10.404
soplex	1232519	8.217	1022869	6.819	827124	5.514

Open-Ended Branch Predictor

The open-ended branch predictor is a GShare predictor. The 15 LSBs of the PC are XORed with a 15-bit global history to produce a 15-bit index. This index is used to access a table with 2^{15} entries, where each entry is a 3-bit saturating counter representing the predictor state.

Storage Calculation:

- The global history requires 2 bytes (uint16_t) to store 15 bits.
- The prediction table requires 32,768 entries × 1 byte per entry = 32,768 bytes
- Total storage is 2 + 32,768 = 32,770 bytes ≈ 32 KB

Upon calculating the average MPKI across the eight provided benchmarks for the open-ended predictor, we see that it is 7.33525.

CACTI Analysis of Branch Predictors

<u>2level</u>

The 2level PaP predictor uses 1 branch history table (BHT) with 512 entries, and 8 pattern history tables (PHT) with 64 entries each. Two RAM modules were used to model this. The -size parameter in `2level-bpred-1.cfg` was set to 512 to represent the BHT. Since each 1 byte entry in a PHT can hold four 2-bit saturating counters, the -size parameter in `2level-bpred-2.cfg` was set to 128 to represent all 8 PHT tables, where $128 = (8*64)/4$. The table below contains the area, access time, and leakage power statistics for both data structures.

	2level-bpred-1.cfg	2level-bpred-2.cfg	Combined
Access time (ns):	0.163585	0.143854	max: 0.163585
Cycle time (ns):	0.117678	0.0950145	max: 0.117678
Total leakage power of a bank (mW)	0.195006	0.0535953	sum: 0.2486013
Cache height x width (mm^2)	0.00105277602	0.00033261422	sum: 0.00138539024

<u>Open-Ended</u>

The Gshare predictor table consists of 2^{15} or 32768 entries, each 1 byte wide. One RAM module was used to model this. The -size parameter in `open-ended-bpred.cfg` was set to 32768. The table below contains the area, access time, and leakage power statistics for the data structure.

Access time (ns):	0.343503
Cycle time (ns):	0.443499
Total leakage power of a bank (mW)	10.3838
Cache height x width (mm^2)	0.04686535823

Statement of Work

Both team members worked on all parts of the lab together.

Appendices

A. Appendix: Benchmark Outputs for B2 50k vs 30k Iterations

B2 50k Iterations:

```
NUM_INSTRUCTIONS      :  2833473
NUM_CONDITIONAL_BR    :   288156

2bitsat: NUM_MISPREDICTIONS   :    64973
2bitsat: MISPRED_PER_1K_INST  :   22.931
2level:  NUM_MISPREDICTIONS   :    36095
2level:  MISPRED_PER_1K_INST  :   12.739
openend: NUM_MISPREDICTIONS   :     2795
openend: MISPRED_PER_1K_INST  :    0.986
```

B2 30k Iterations:

```
NUM_INSTRUCTIONS      :  2503476
NUM_CONDITIONAL_BR    :   248156

2bitsat: NUM_MISPREDICTIONS   :    56064
2bitsat: MISPRED_PER_1K_INST  :   22.394
2level:  NUM_MISPREDICTIONS   :    22501
2level:  MISPRED_PER_1K_INST  :    8.988
openend: NUM_MISPREDICTIONS   :     2792
openend: MISPRED_PER_1K_INST  :    1.115
```