ECE486/586

Computer Architecture

Final Project Report for Branch and Branch Target Prediction

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CONTENT

1. Project Specifications

Branch and Branch Target Prediction

1. Branch Predictor - Implementation of Alpha 21264 branch predictor
2. Brach Target Predictor – Design and simulation of branch target predictor

Design Constraints:

- ***Memory Limit:*** Maximum 8K bytes of storage (total, including the Alpha predictor)
- ***Table sizes:*** All tables must be sized as powers of two.
- ***Associative tables***: ≤ 8 way
- Random replacement must be reproducible.
- All multiplying or dividing numbers must be in powers of two.

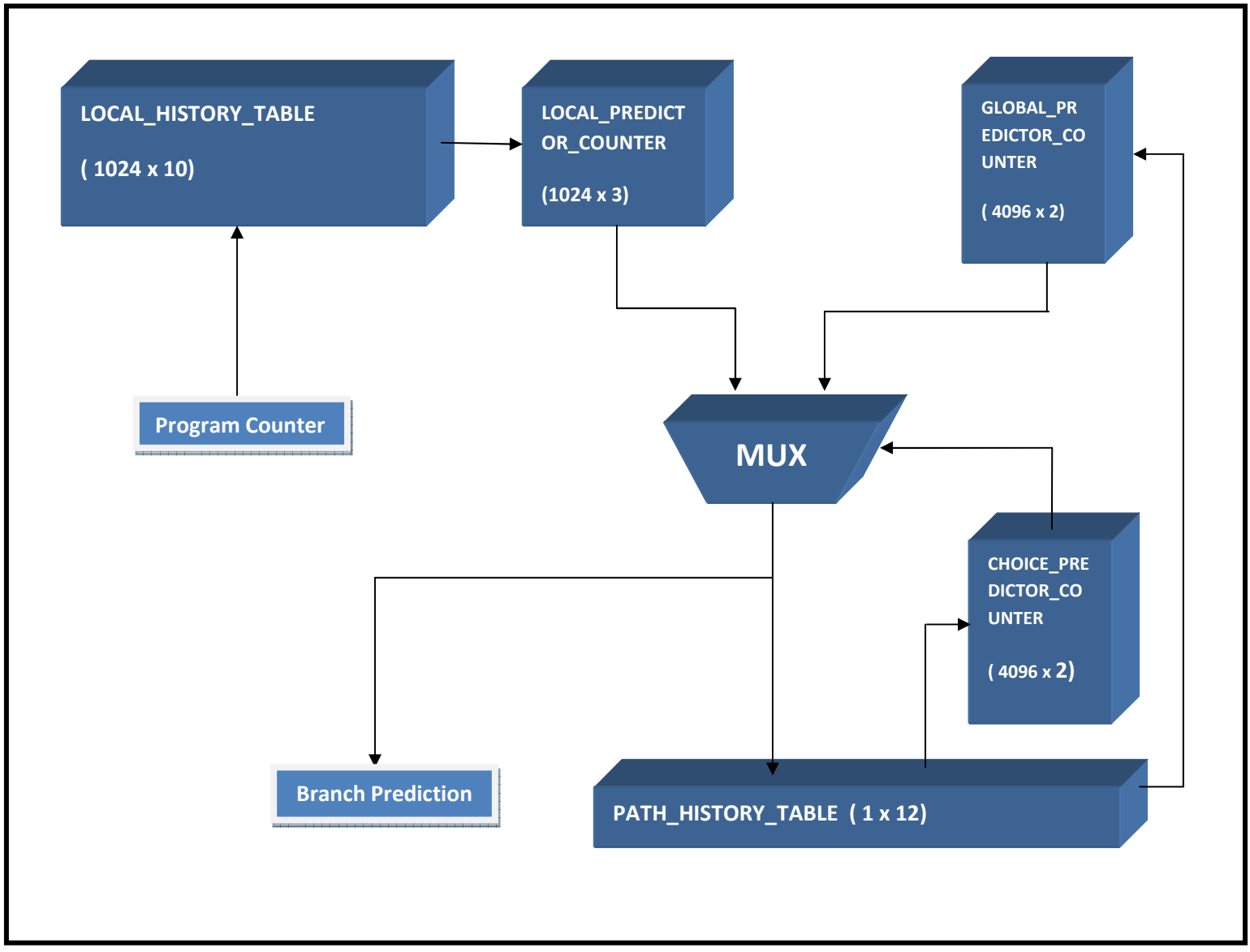
2. Assumptions

- Program counter is at most 32 bits wide.
- Size of an instruction is not fixed
- Instructions may not be aligned to any fixed size.

3. ALPHA Predictor Implementation

The Alpha 21264 branch predictor uses both local correlation and global correlation. To implement this, ALPHA predictor allocates dedicated memory to maintain local branch history and global branch history. To predict the direction of the current branch, the 21264 implements a tournament branch prediction counter to select between the local predictor and global predictor. Together, local and global correlation techniques improve prediction rate.

a. Block Diagram



Tournament Branch Predictor:

1. Local Branch Predictor:
    a. A local history table contains the past 10 outcome of the particular branch.
    b. A pattern history table contains 1024 entries.
    c. A 3-bit saturating counter for each entry in the pattern history table.
2. Global Branch Predictor:
    a. A global history register contains the outcome of the past 12 branches.
    b. A pattern history table contains 4096 entries.
    c. A 2-bit saturating counter for each entry in the pattern history table.
3. Choice Predictor Counter:
    a. A 2-bit saturating counter chooses which of the two branch predictors to use for each branch.

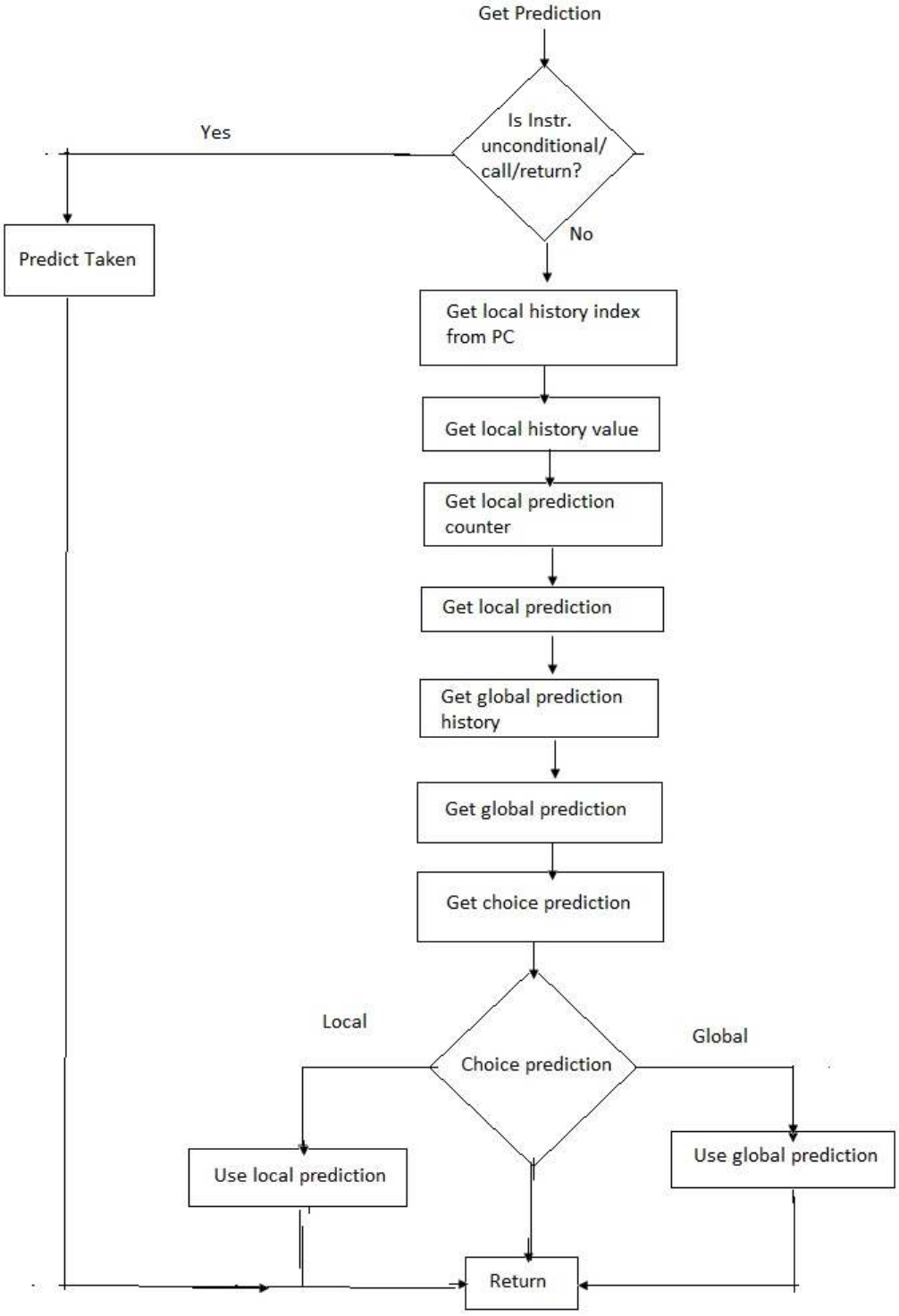
b. Memory Management:

Sr. No	Memory Blocks	Indexed By	Size (bits)
1	LOCAL_HISTORY_TABLE	**MEM**[PROGRAM COUNTER]	1024 x 10
2	LOCAL_PREDICTOR_COUNTER	**MEM**[LOCAL_HISTORY_TABLE]	1024 x 03
3	GLOBAL_PATH HISTRORY_TABLE		1 x 12
4	GLOBAL_PREDICTOR_COUNTER	**MEM**[GLOBAL_PATH_HISTORY_TABLE]	4096 x 02
5	CHOICE_PREDICTOR_COUNTER	**MEM**[GLOBAL_PATH_HISTORY_TABLE]	4096 x 02
		TOTAL MEMORY USED	**29708**

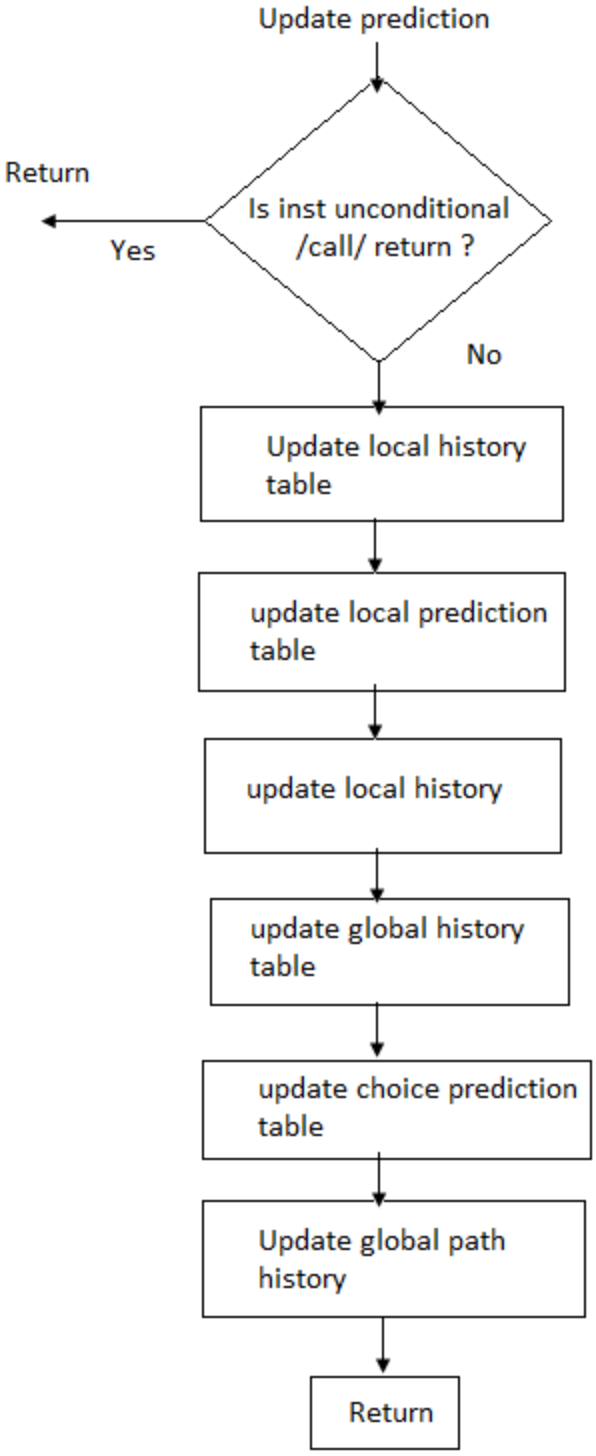
This is well within the constraint of 8K bytes (65536 bits)

c. Flow Chart:

1. Get Branch Prediction



2. Update Branch Prediction



d. Testing Strategy:

To test the branch predictor code we have considered two cases.

Case I: Single branch with execution pattern: **T N N N N N N N N N -----**To Test Local Correlations

Case II: 3 correlative conditional branches A, B & C ----------To Test Global Correlation

```
If ( A==0)
{
        //Code for A
}
If ( B==0)
{
        //Code for B
}
If( A==B)
{
        //Code for C
}
```

If A -> Taken & B-> taken then C-> must be Taken.
The test cases were generated using a custom framework for test generation.

e. Test Results:

-- Appendix b.

f. Benchmark Results:

Sr No	Benchmark	Tracefile	Total Wrong cc Predicts / 1000 insts	Total Wrong target Predicts / 1000 insts *
1	Floating Point	DIST-FP-1.bz2	3.364	23.519
2	Floating Point	DIST-FP-2.bz2	1.334	12.913
3	Floating Point	DIST-FP-3.bz2	0.516	7.373
4	Floating Point	DIST-FP-4.bz2	0.264	4.644
5	Floating Point	DIST-FP-5.bz2	2.245	36.337
6	Integer	DIST-INT-1.bz2	8.537	64.702
7	Integer	DIST-INT-2.bz2	11.842	56.589
8	Integer	DIST-INT-3.bz2	12.619	54.217
9	Integer	DIST-INT-4.bz2	2.898	28.422
10	Integer	DIST-INT-5.bz2	0.484	4.999
11	Multimedia	DIST-MM-1.bz2	8.858	41.29
12	Multimedia	DIST-MM-2.bz2	10.816	91.962
13	Multimedia	DIST-MM-3.bz2	1.598	116.523
14	Multimedia	DIST-MM-4.bz2	2.141	146.874
15	Multimedia	DIST-MM-5.bz2	6.398	67.252
16	Server	DIST-SERV-1.bz2	9.793	96.818
17	Server	DIST-SERV-2.bz2	10.171	94.361
18	Server	DIST-SERV-3.bz2	8.129	93.976
19	Server	DIST-SERV-4.bz2	10.938	113.355
20	Server	DIST-SERV-5.bz2	11.549	115.392
		Geometric mean	**3.855**	**43.244**

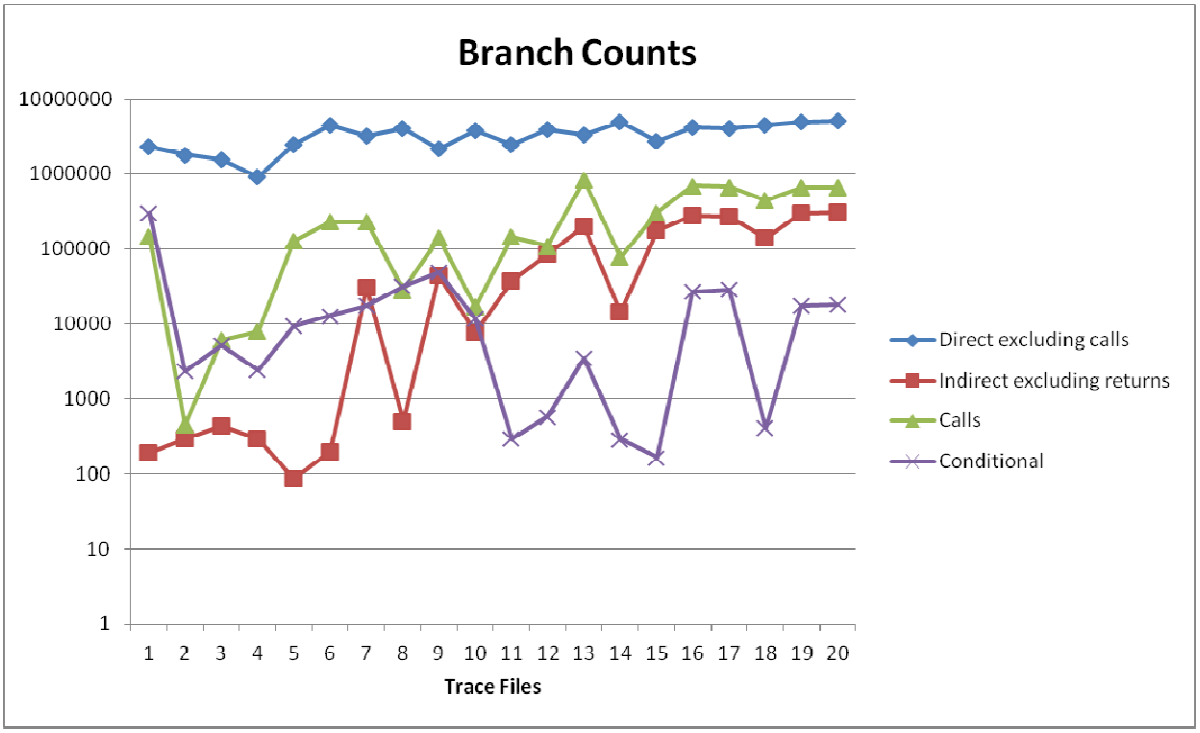
*Please note that the Branch predictor has no effect on the target predictions.

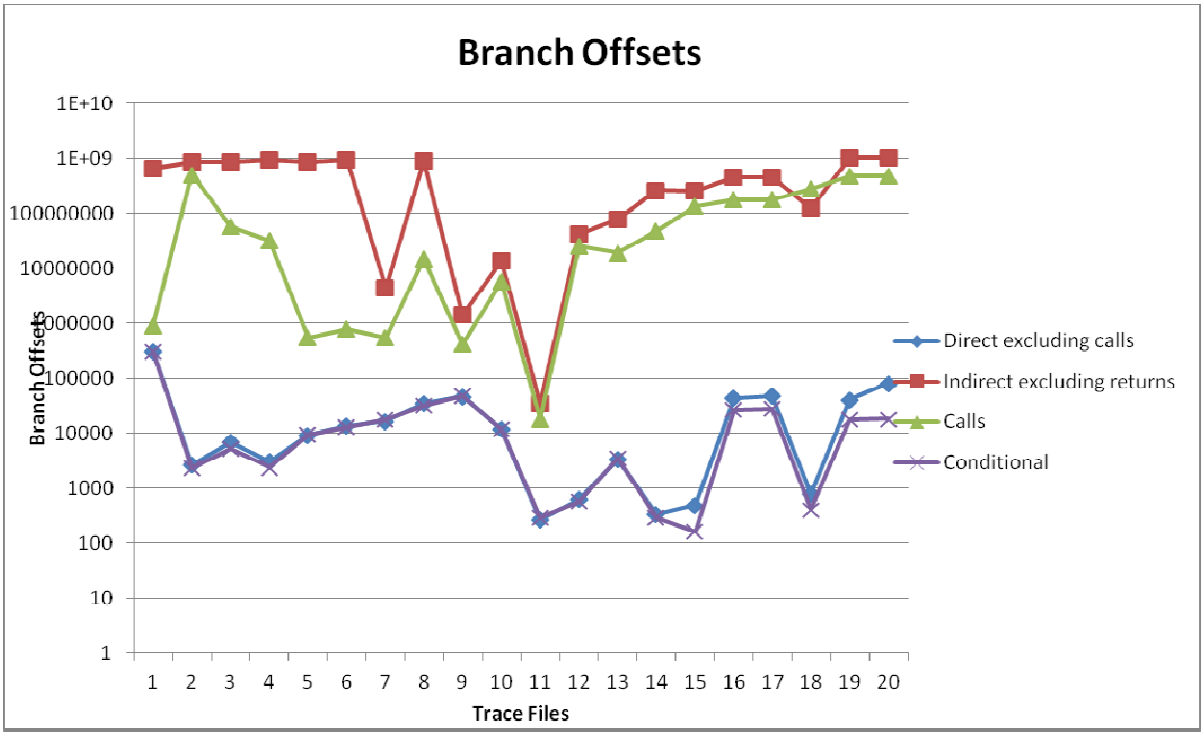
4. Enhanced Alpha Predictor with BTB design

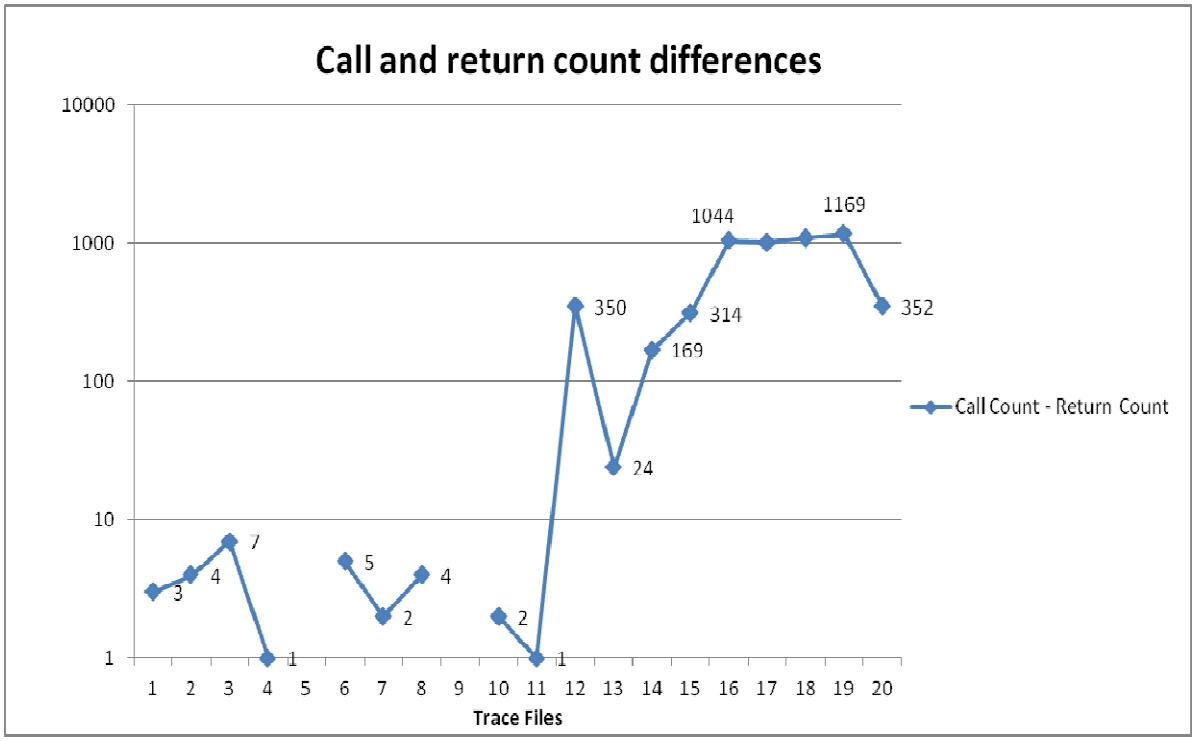
a. Trace File Analysis:

We have modified the given perl script and the framework to obtain the data related to all branches. We have used this strategy to exploit this information for designing the **Branch Target Buffer.**
For branch offsets and call and return differences, each point is the average value of that parameter within that trace file.
We extracted the following results:

1. Branch counts for each type of branches
2. Average Branch offsets
3. Average Call and return count differences



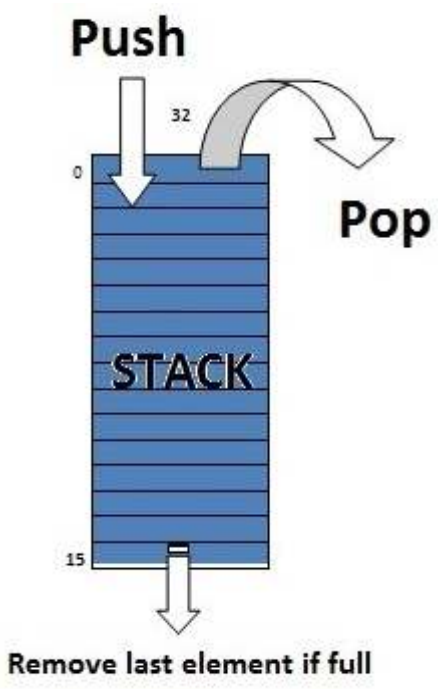

Branch Offsets
1E+10
1E+09
100000000
10000000
1000000
100000
10000
1000
100
10
1
Branch Offsets
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Trace Files
Direct excluding calls
Indirect excluding returns
Calls
Conditional


Call and return count differences
10000
1000
100
10
1
3
4
7
1
5
2
4
2
1
350
24
169
314
1044
1169
352
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Trace Files
Call Count - Return Count

Observations:

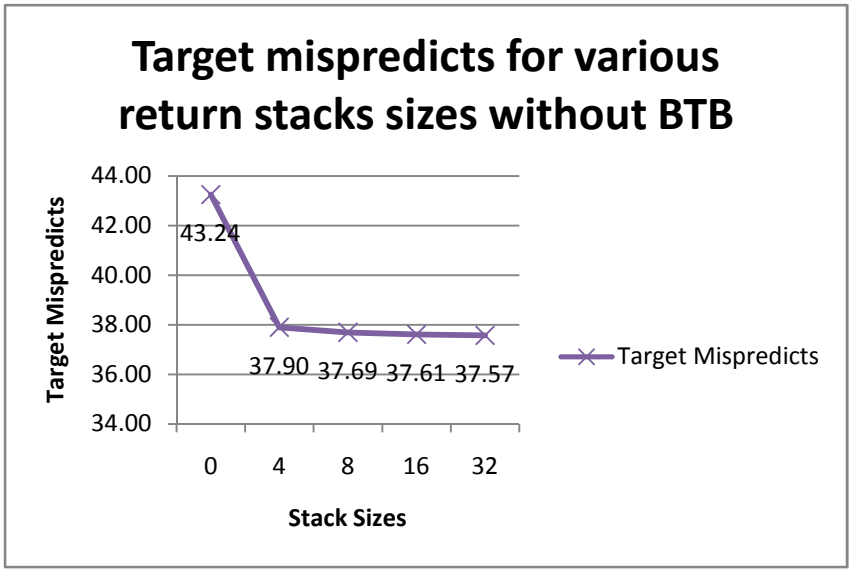
1. The branch count for the direct branches is the highest. They are larger by almost two orders of magnitude as compared to other branch types.
2. The offset for direct branches offset is also minimum. The offset can fit into 17 bits.
3. Counts for the Call and return branches provide an estimate for the return stack size.

b. Design (Design Variations Vs Prediction Performance)



Return Stack Design

We designed a return stack such that if it is becomes full, the first pushed element is removed. We obtained performance characteristics for various stack sizes: 0 (no stack at all) to 16 deep. Using the perl script we obtained the geometric mean for target mispredicts in all 20 trace files, for various stack sizes, absence of any branch target buffer



Stack size of 16 provides optimum balance between performance and space required.

c. Design of Branch target buffer

From the trace file analysis, we concluded that a majority of branch offsets can fit within a 17 bit range. Thus we chose a direct mapped table 32 bits wide with 512 entries. The 17 bits are used for branch offsets and 15 bits for the program counter tag1 bits. Since the table is 512 deep, we get index bits of 9 bits from the program counter. Thus, the remaining 8 bits (tag2) are stored in another table (direct mapped) that is 512 deep with each entry 8 bits wide.

Figure 1: Offset Table

Figure 2: Tag bits table

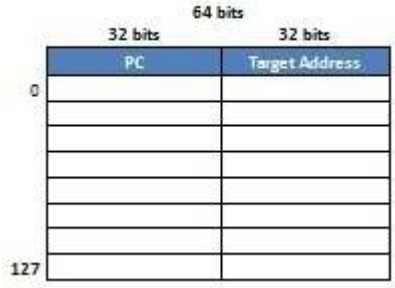


Figure 3: Fully associative table 1

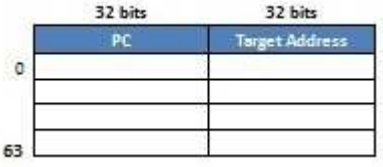


Figure 4: Fully associative table 2

In the space left, we used two fully associative tables that store complete program counter for any branch, without indexing.

Replacement policy:

The last entry in this fully associative table is removed and other entries are shifted down. The new item is placed in the first slot.

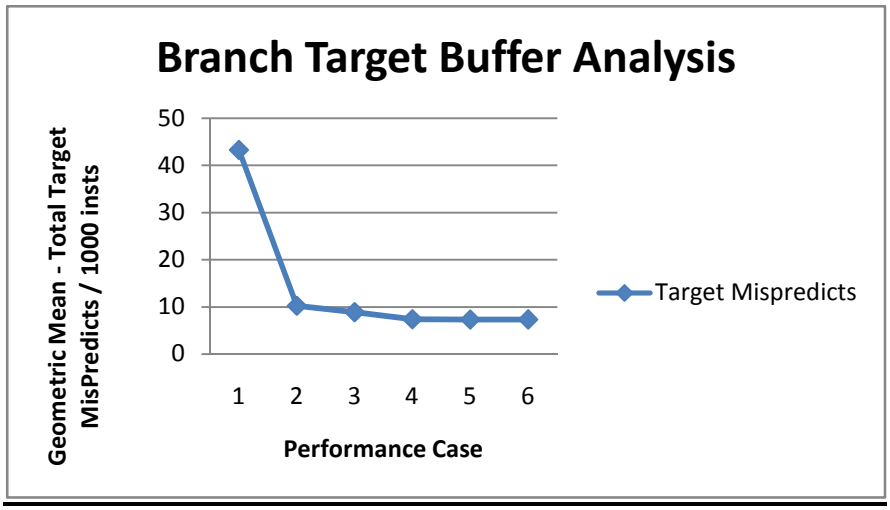
In order to improve the branch predictor's performance, we have increased the local prediction counter's size from 3 bit to 4 bit by doing this we have also utilized the available memory effectively. This increases the branch predictor memory requirement by 1024 bits.

Memory requirement for target predictor:

Table	Number of unique branches	Memory (bits)
Offset Table	512	16384
Tag bits table	0	4096
Fully associative table 1	128	8192
Fully associative table 2	64	2048
Local History table	-	10240
Local Prediction table	-	4096
Global Prediction table	-	8192
Choice prediction table	-	8192
Global path history	-	12
Total	**704**	**61452**

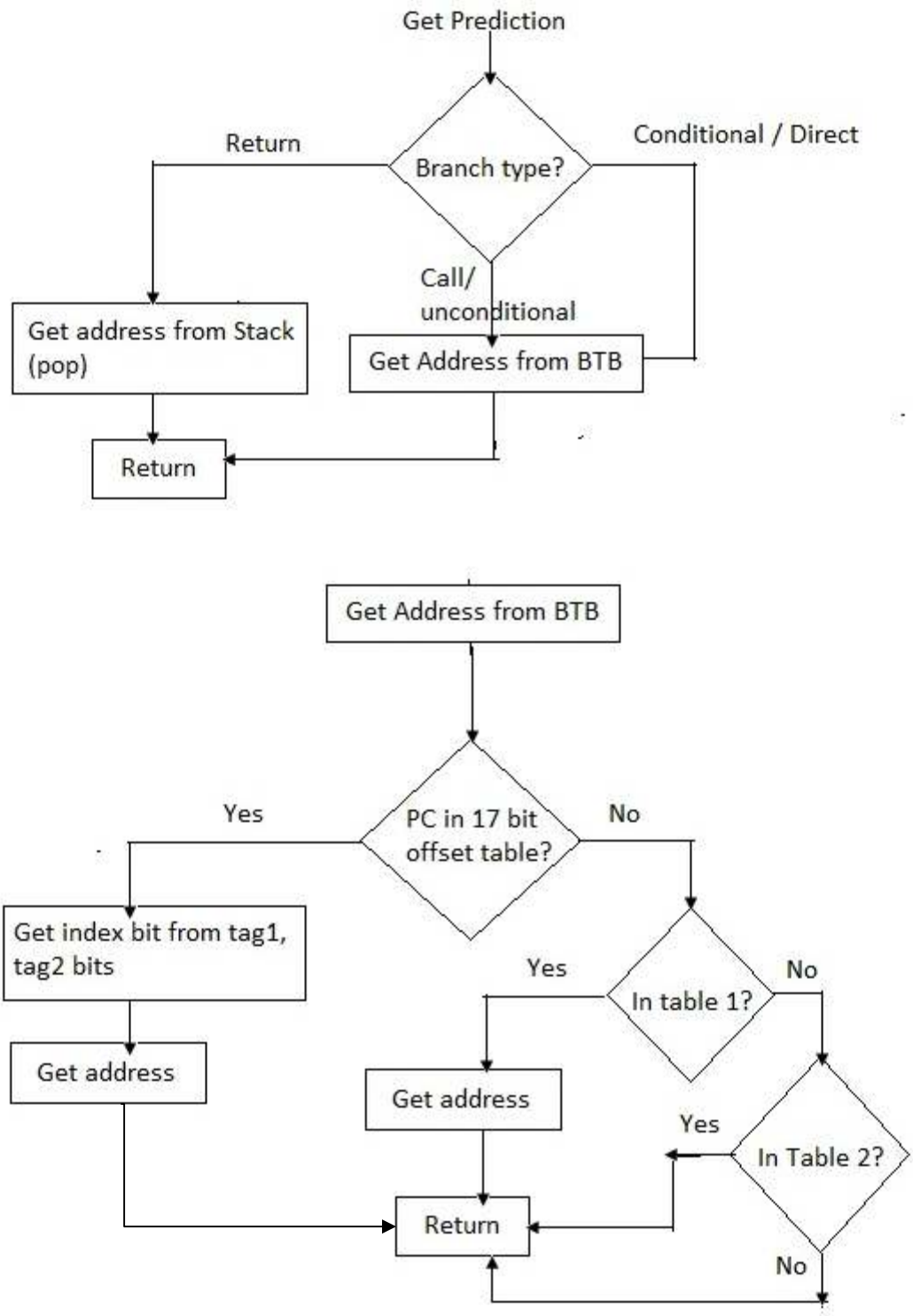
We saved 65536 - 61452 = 4084 bits.

d. Performance Cases:

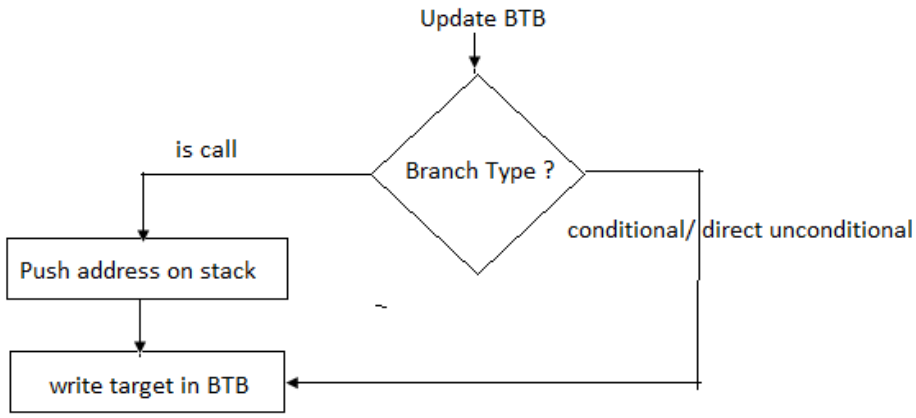


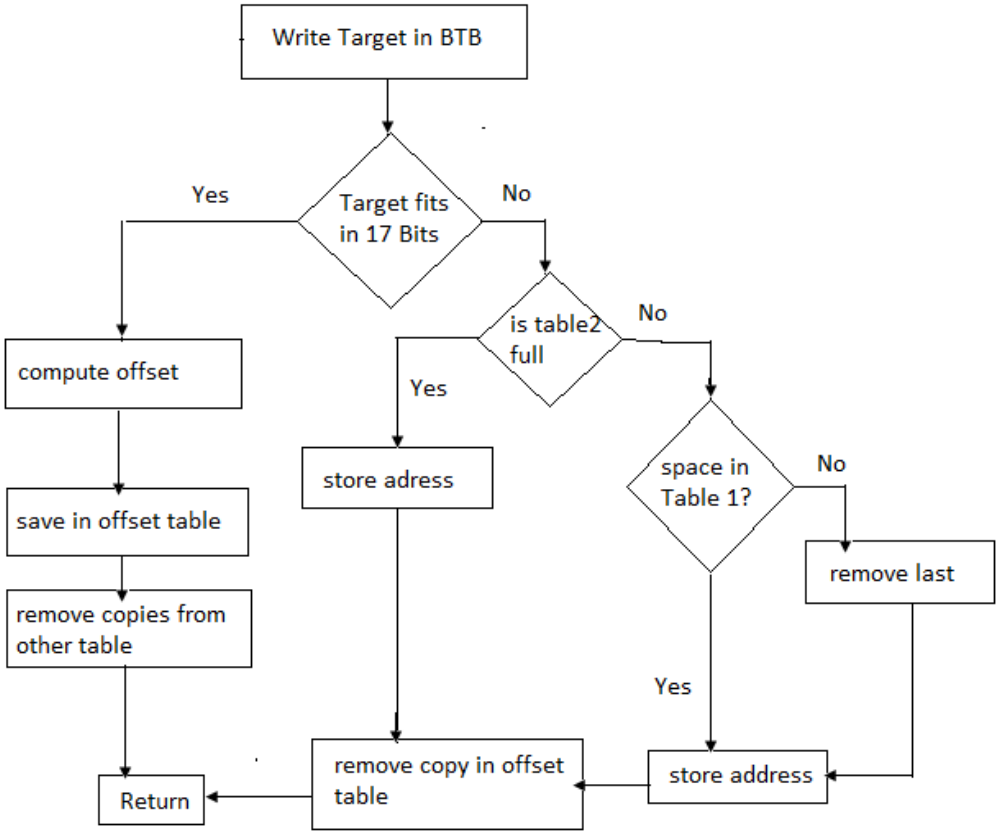
Case	Performance Case Description						Prediction Performance (Total Wrong Predicts / 1000 instructions)	
	Changes In Alpha Branch Predictor	Changes in BTB					Branch Prediction	Branch Target Prediction
		Offset BTB Size	Tag Bits table	Fully Associative Table 1 Size	Fully Associative Table 2 Size	Stack for Return branch		
Case 1	No	Without BTB					3.855502454	43.24417785
Case2	No	512 x (32 + 32) bits	NA	NA	NA	32 x 16 bits	3.855502454	10.20245655
Case 3	No	512 x (16 + 16) bits	512 x 8 bits	NA	NA	32 x 16 bits	3.855502454	8.857686195
Case 4	No	512 x (17 + 15) bits	512 x 8 bits	128 x (32 + 32) bits	64 x (32 + 32) bits	32 x 16 bits	3.855502454	7.340589735
Case 5	Yes - 4 Bit Local Prediction Counter	512 x (17 + 15) bits	512 x 8 bits	128 x (32 + 32) bits	64 x (32 + 32) bits	32 x 16 bits	3.838446283	7.293957785
Case 6	4 Bit Local prediction counter + 11 bit Global History Table	512 x (17 + 15) bits	512 x 8 bits	256 x (32 + 32) bits	64 x (32 + 32) bits	32 x 16 bits	4.043052555	7.307459419

e. Flow chart for Get Prediction



Flow chart for update prediction





5. Development environment

We used the Eclipse IDE designing and debugging our target predictor simulator. We used the make files provided in the framework, and not the Eclipse auto generated makefiles. The compiler used was Mingw port of the GNU g++ running on the Cygwin environment on the windows platform.

6. Repository

We used Subversion for source control. The repository is hosted on Google Code and provides up to 5 GB space for hosting projects. All previous revisions can be easily obtained via the repository. It also contains an issue tracking system for managing defects.

7. Appendix

a. Source code:

b. Trace file analysis result