

CS 461/561  
Computer Architecture  
Fall 2013

Homework #5

DUE: November 20, 2013

## Questions

### Part 1 – Static Branch Predictor

1. Which of these two policies is more accurate (has fewer mispredictions)?

The prediction of always not taken is better, because it predicted 62% correct. This is because there are more not taken branches in the trace file and the counters are all initially set to 0.

2. Based on what you know about common programming paradigms, what might explain the above result?

Boolean values, in most languages today, are almost always false when they are created. Since, always-not-taken is testing against false values, the outcome for most of the conditions will be true.

### Part 2 – 2-Bit Bimodal Dynamic Branch Predictor

1. Given a large enough predictor, what is the best misprediction rate obtainable by the bimodal predictor?

The 14-bit (16K) had the best misprediction rate at 10.76, but if the BHT size was increased to store 18 bits (256K), the misprediction rate would drop to 11.05%.

2. How large must the predictor be to reduce the number of mispredictions by approximately half as compared to the better of "always taken" and "always not taken"? Give the predictor size both in terms of number of counters as well as bytes.
  - **Always Taken: Mispredictions** - 10,204,684 (Half = 5,102,342)
    - **128B BHT** mispredicted 4,097,609 times; less than half.
  - **Always Not-Taken Mispredictions** - 6,211,595 (Half = 3,105,792)
    - **512B BHT** mispredicted 3,110,140 times - This is a little more than half, but if the BHT size was increased to 1K, the mispredictions would fall to 2,618,105; which is significantly lower.
3. At what point does the performance of the predictor pretty much max out? That is, how large does the predictor need to be before it basically captures almost all of the benefit of a much larger predictor.

The performance of the predictor maxes out at around 256K with a misprediction rate of 11.05%.

### Part 3- Correlating Prediction using Global Branch History

1. Given a large enough predictor, what is the best misprediction rate obtainable by this gshare predictor?

The 18-Bit Branch History Table (256K) mispredicted only 10.38% of the time.

2. At what table size is the gshare predictor generally better than the simple bimodal predictor?

At 4K, the GShare overtakes the Bimodal predictor as the most favorable predictor.

3. Contrast the performance of the various configurations of predictors (bimodal, gshare). Are there instances where gshare is sometimes more accurate than bimodal and vice versa? Can you explain why this may occur?

Bimodal performed 1-2% better than the GShare up until the BHT size grew to be 1K in size, where they performed about the same. After the table grew larger than 2K, the GShare began to have fewer mispredictions.

## Part 4 – Correlating Prediction Using Two-Level Prediction

1. After collecting information on the simulation of this branch predictor design, contrast its performance with the previous branch prediction schemes. How does this design compare in terms of misprediction rates with other outcomes?

The two-level correlating predictor does very well compared to the other two predictors. Since the BHT is replicated 4 times, the overall BHT size for each table only needs to be  $\frac{1}{2}$  of the size to perform on the same level. Since the same address is repeated 4 times, the chance of decrementing a counter is reduced. All of the dynamic predictors that were used in these performance tests maxed out at 256K. After that the prediction rates were constant. Each of the predictors ended up deviating between 1-2% of one another.

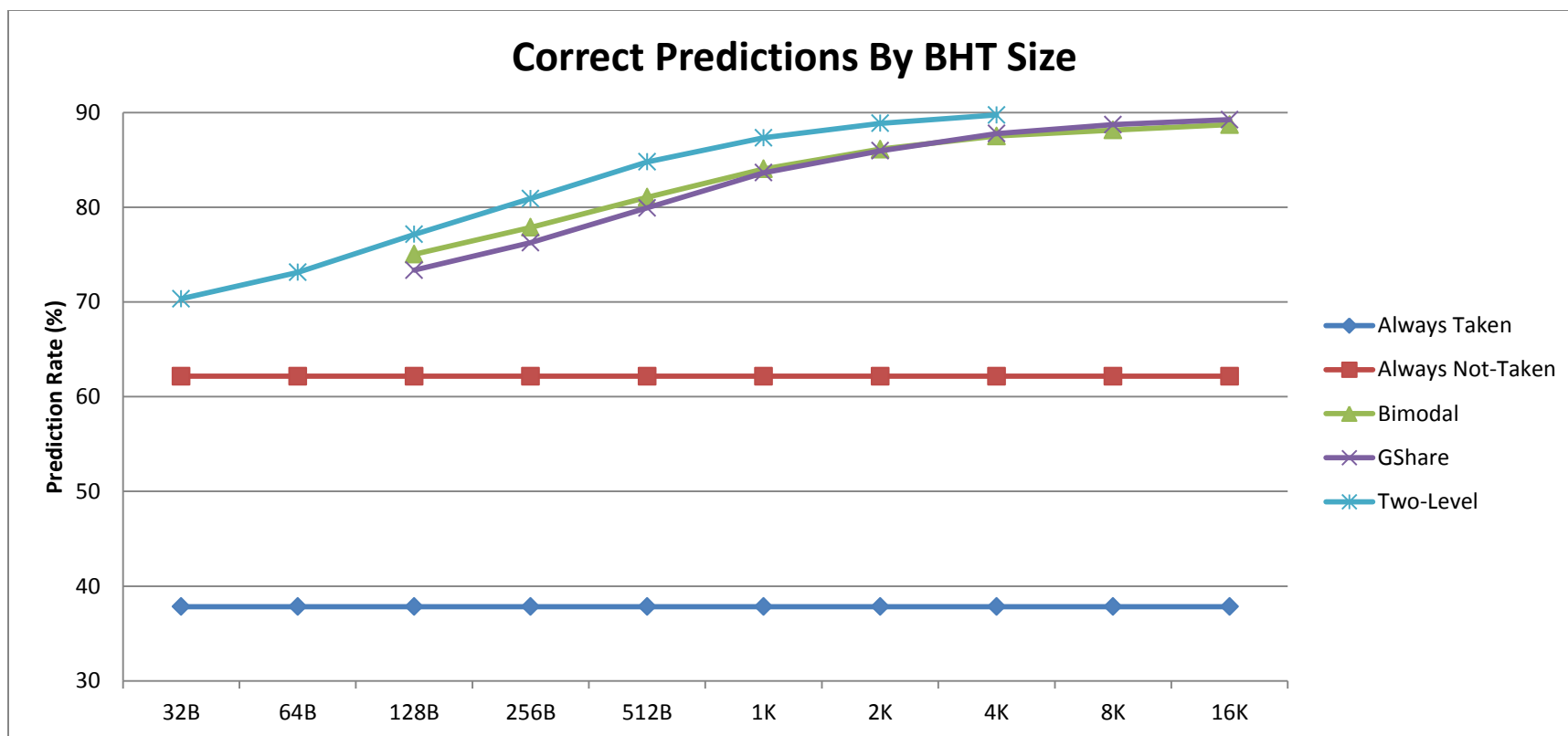
## Appendix

Predictor \ BHT Size	32B	64B	128B	256B	512B	1K	2K	4K	8K	16K	Mean	S Deviation	S Variance	P Deviation	P Variance
<b>Always Taken</b>	37.84	37.84	37.84	37.84	37.84	37.84	37.84	37.84	37.84	37.84	-	-	-	-	-
<b>Always Not-Taken</b>	62.16	62.16	62.16	62.16	62.16	62.16	62.16	62.16	62.16	62.16	-	-	-	-	-
<b>Bimodal</b>			75.04	77.87	81.05	84.05	86.12	87.52	88.15	88.71	83.5638	5.0897	25.9046	4.7609	22.6665
<b>GShare</b>			73.35	76.26	79.93	83.64	85.95	87.77	88.72	89.24	83.1075	5.9929	35.9148	5.6058	31.4254
<b>Two-Level</b>	70.34	73.13	77.13	80.92	84.78	87.33	88.86	89.74			81.5288	7.3761	54.4062	6.8997	47.6055

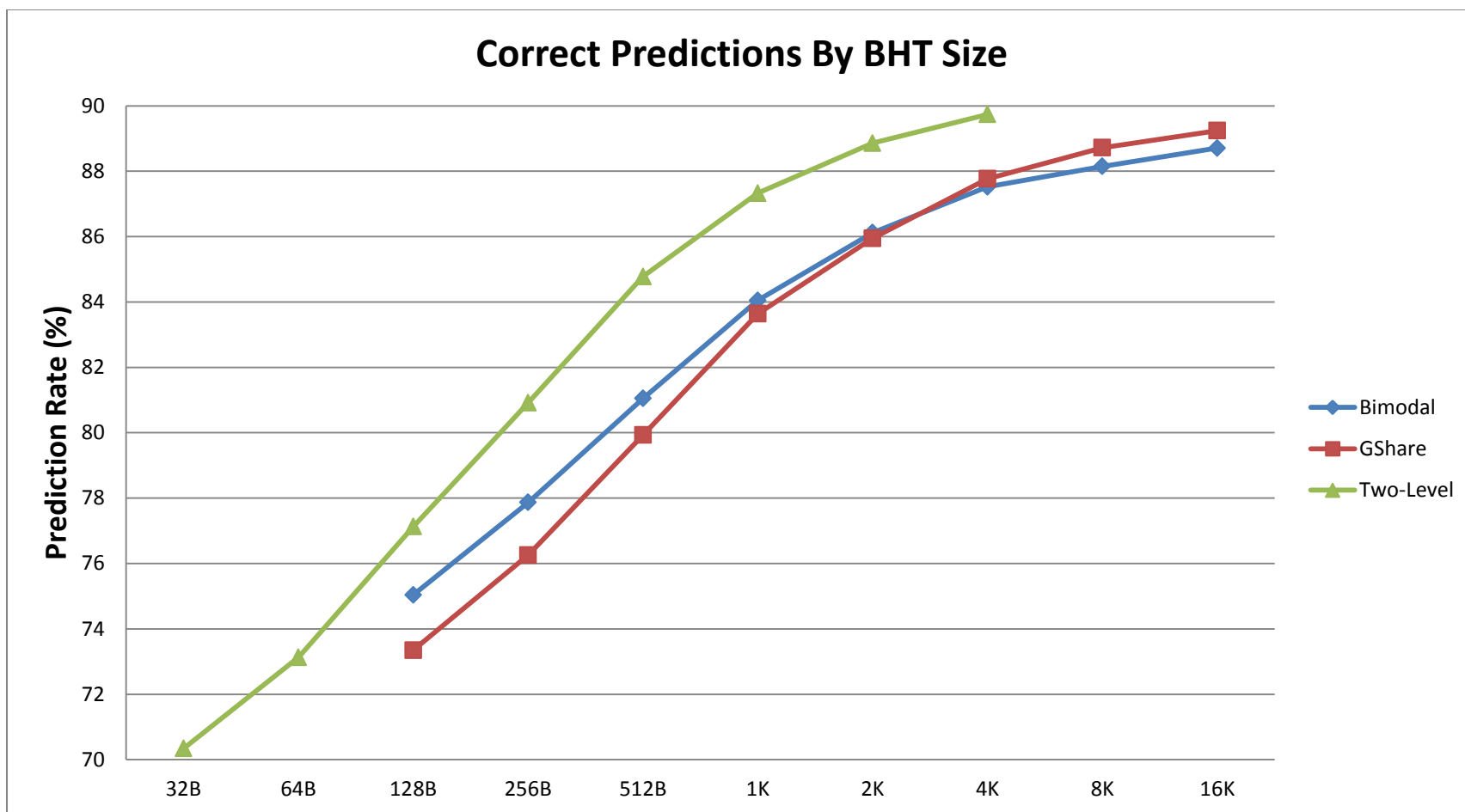
**Table 1:** Correct prediction rates for dynamic predictors.

Predictor Size [32B - 16M]	Bimodal	Gshare	Two-Level
<b>Sample Standard Deviation, s:</b>	6.1836	7.1036	6.2988
<b>Sample Standard Variance, s<sup>2</sup></b>	38.2369	50.4605	39.6754
<b>Total Numbers, N</b>	20	20	20
<b>Sum:</b>	1700.3900	1700.1600	1736.3400
<b>Mean (Average):</b>	85.0195	85.0080	86.8170
<b>Population Standard Deviation, <math>\sigma</math></b>	6.0270	6.9237	6.1394
<b>Population Standard Variance, <math>\sigma^2</math></b>	36.3250	47.9374	37.6916

**Table 2:** Statistics for dynamic branch predictors for BHT sizes ranging from 5 bits up to 24 bits.



**Figure 1:** Correct prediction rates for static and dynamic branch predictors.



**Figure 2:** Correct prediction rates for dynamic branch predictors.

## Raw Data

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Static Branch Predictor - Always Taken		Branch History Table Size: 8K	
-----		Correct Prediction : 14564688 / 16416279 or %88.72	
Always Taken : true		Misprediction : 1851591 / 16416279 or %11.28	
Correct Prediction : 6211595 / 16416279 or %37.84		-----	
Misprediction : 10204684 / 16416279 or %62.16		Branch History Table Size: 16K	
-----		Correct Prediction : 14649273 / 16416279 or %89.24	
		Misprediction : 1767006 / 16416279 or %10.76	
		-----	
Static Branch Predictor - Always Not Taken		Branch History Table Size: 32K	
-----		Correct Prediction : 14683319 / 16416279 or %89.44	
Always Taken : false		Misprediction : 1732960 / 16416279 or %10.56	
Correct Prediction : 10204684 / 16416279 or %62.16		-----	
Misprediction : 6211595 / 16416279 or %37.84		Branch History Table Size: 64K	
-----		Correct Prediction : 14697200 / 16416279 or %89.53	
		Misprediction : 1719079 / 16416279 or %10.47	
		-----	
		Branch History Table Size: 128K	
		Correct Prediction : 14699765 / 16416279 or %89.54	
		Misprediction : 1716514 / 16416279 or %10.46	
		-----	
Bimodal Branch Predictor		Branch History Table Size: 256K	
-----		Correct Prediction : 14711671 / 16416279 or %89.62	
Branch History Table Size: 32B		Misprediction : 1704608 / 16416279 or %10.38	
Correct Prediction : 11543027 / 16416279 or %70.31		-----	
Misprediction : 4873252 / 16416279 or %29.69		Branch History Table Size: 512K	
-----		Correct Prediction : 14711945 / 16416279 or %89.62	
Branch History Table Size: 64B		Misprediction : 1704334 / 16416279 or %10.38	
Correct Prediction : 11881980 / 16416279 or %72.38		-----	
Misprediction : 4534299 / 16416279 or %27.62		Branch History Table Size: 1M	
-----		Correct Prediction : 14712537 / 16416279 or %89.62	
Branch History Table Size: 128B		Misprediction : 1703742 / 16416279 or %10.38	
Correct Prediction : 12318670 / 16416279 or %75.04		-----	
Misprediction : 4097609 / 16416279 or %24.96		Branch History Table Size: 2M	
-----		Correct Prediction : 14712600 / 16416279 or %89.62	
Branch History Table Size: 256B		Misprediction : 1703679 / 16416279 or %10.38	
Correct Prediction : 12783932 / 16416279 or %77.87		-----	
Misprediction : 3632347 / 16416279 or %22.13		Branch History Table Size: 4M	
-----		Correct Prediction : 14712600 / 16416279 or %89.62	
Branch History Table Size: 512B		Misprediction : 1703679 / 16416279 or %10.38	
Correct Prediction : 13306139 / 16416279 or %81.05		-----	
Misprediction : 3110140 / 16416279 or %18.95		Branch History Table Size: 8M	
-----		Correct Prediction : 14712600 / 16416279 or %89.62	
Branch History Table Size: 1K		Misprediction : 1703679 / 16416279 or %10.38	
Correct Prediction : 13798174 / 16416279 or %84.05		-----	
Misprediction : 2618105 / 16416279 or %15.95		Branch History Table Size: 16M	
-----		Correct Prediction : 14712600 / 16416279 or %89.62	
Branch History Table Size: 2K		Misprediction : 1703679 / 16416279 or %10.38	
Correct Prediction : 14137802 / 16416279 or %86.12		-----	
Misprediction : 2278477 / 16416279 or %13.88			
-----		Two-Level Branch Predictor	
Branch History Table Size: 4K		-----	
Correct Prediction : 14368276 / 16416279 or %87.52		Branch History Table Size: 32B	
Misprediction : 2048003 / 16416279 or %12.48		Correct Prediction : 11547966 / 16416279 or %70.34	
-----		Misprediction : 4868313 / 16416279 or %29.66	
Branch History Table Size: 8K		-----	
Correct Prediction : 14470560 / 16416279 or %88.15		Branch History Table Size: 64B	
Misprediction : 1945719 / 16416279 or %11.85		Correct Prediction : 12005448 / 16416279 or %73.13	
-----		Misprediction : 4410831 / 16416279 or %26.87	
Branch History Table Size: 16K		-----	
Correct Prediction : 14562263 / 16416279 or %88.71		Branch History Table Size: 128B	
Misprediction : 1854016 / 16416279 or %11.29		Correct Prediction : 12662558 / 16416279 or %77.13	
-----		Misprediction : 3753721 / 16416279 or %22.87	
Branch History Table Size: 32K		-----	
Correct Prediction : 14576368 / 16416279 or %88.79		Branch History Table Size: 256B	
Misprediction : 1839911 / 16416279 or %11.21		Correct Prediction : 13283258 / 16416279 or %80.92	
-----		Misprediction : 3133021 / 16416279 or %19.08	
Branch History Table Size: 64K		-----	
Correct Prediction : 14588954 / 16416279 or %88.87		Branch History Table Size: 512B	
Misprediction : 1827325 / 16416279 or %11.13		Correct Prediction : 13917348 / 16416279 or %84.78	
-----		Misprediction : 2498931 / 16416279 or %15.22	
Branch History Table Size: 128K		-----	
Correct Prediction : 14591334 / 16416279 or %88.88		Branch History Table Size: 1K	
Misprediction : 1824945 / 16416279 or %11.12		Correct Prediction : 14336621 / 16416279 or %87.33	
-----		Misprediction : 2079658 / 16416279 or %12.67	
Branch History Table Size: 256K		-----	
Correct Prediction : 14602207 / 16416279 or %88.95		Branch History Table Size: 2K	
Misprediction : 1814072 / 16416279 or %11.05		Correct Prediction : 14587037 / 16416279 or %88.86	
-----		Misprediction : 1829242 / 16416279 or %11.14	
Branch History Table Size: 512K		-----	
Correct Prediction : 14602141 / 16416279 or %88.95		Branch History Table Size: 4K	
Misprediction : 1814138 / 16416279 or %11.05		Correct Prediction : 14732146 / 16416279 or %89.74	
-----		Misprediction : 1684133 / 16416279 or %10.26	
Branch History Table Size: 1M			
Correct Prediction : 14602465 / 16416279 or %88.95			
Misprediction : 1813814 / 16416279 or %11.05			

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Branch History Table Size: 2M
Correct Prediction      : 14602464 / 16416279 or %88.95
Misprediction          : 1813815 / 16416279 or %11.05
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Branch History Table Size: 4M
Correct Prediction      : 14602464 / 16416279 or %88.95
Misprediction          : 1813815 / 16416279 or %11.05
-----
Branch History Table Size: 8M
Correct Prediction      : 14602464 / 16416279 or %88.95
Misprediction          : 1813815 / 16416279 or %11.05
-----
Branch History Table Size: 16M
Correct Prediction      : 14602464 / 16416279 or %88.95
Misprediction          : 1813815 / 16416279 or %11.05
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-----
GShare Branch Predictor
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Branch History Table Size: 32B
Correct Prediction      : 11291270 / 16416279 or %68.78
Misprediction          : 5125009 / 16416279 or %31.22
-----
Branch History Table Size: 64B
Correct Prediction      : 11600748 / 16416279 or %70.67
Misprediction          : 4815531 / 16416279 or %29.33
-----
Branch History Table Size: 128B
Correct Prediction      : 12041659 / 16416279 or %73.35
Misprediction          : 4374620 / 16416279 or %26.65
-----
Branch History Table Size: 256B
Correct Prediction      : 12519723 / 16416279 or %76.26
Misprediction          : 3896556 / 16416279 or %23.74
-----
Branch History Table Size: 512B
Correct Prediction      : 13120728 / 16416279 or %79.93
Misprediction          : 3295551 / 16416279 or %20.07
-----
Branch History Table Size: 1K
Correct Prediction      : 13731333 / 16416279 or %83.64
Misprediction          : 2684946 / 16416279 or %16.36
-----
Branch History Table Size: 2K
Correct Prediction      : 14110201 / 16416279 or %85.95
Misprediction          : 2306078 / 16416279 or %14.05
-----
Branch History Table Size: 4K
Correct Prediction      : 14408715 / 16416279 or %87.77
Misprediction          : 2007564 / 16416279 or %12.23

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Branch History Table Size: 8K
Correct Prediction      : 14781972 / 16416279 or %90.04
Misprediction          : 1634307 / 16416279 or %9.96
-----
Branch History Table Size: 16K
Correct Prediction      : 14818214 / 16416279 or %90.27
Misprediction          : 1598065 / 16416279 or %9.73
-----
Branch History Table Size: 32K
Correct Prediction      : 14829249 / 16416279 or %90.33
Misprediction          : 1587030 / 16416279 or %9.67
-----
Branch History Table Size: 64K
Correct Prediction      : 14835022 / 16416279 or %90.37
Misprediction          : 1581257 / 16416279 or %9.63
-----
Branch History Table Size: 128K
Correct Prediction      : 14836011 / 16416279 or %90.37
Misprediction          : 1580268 / 16416279 or %9.63
-----
Branch History Table Size: 256K
Correct Prediction      : 14838240 / 16416279 or %90.39
Misprediction          : 1578039 / 16416279 or %9.61
-----
Branch History Table Size: 512K
Correct Prediction      : 14838216 / 16416279 or %90.39
Misprediction          : 1578063 / 16416279 or %9.61
-----
Branch History Table Size: 1M
Correct Prediction      : 14838496 / 16416279 or %90.39
Misprediction          : 1577783 / 16416279 or %9.61
-----
Branch History Table Size: 2M
Correct Prediction      : 14838498 / 16416279 or %90.39
Misprediction          : 1577781 / 16416279 or %9.61
-----
Branch History Table Size: 4M
Correct Prediction      : 14838498 / 16416279 or %90.39
Misprediction          : 1577781 / 16416279 or %9.61
-----
Branch History Table Size: 8M
Correct Prediction      : 14838498 / 16416279 or %90.39
Misprediction          : 1577781 / 16416279 or %9.61
-----
Branch History Table Size: 16M
Correct Prediction      : 14838498 / 16416279 or %90.39
Misprediction          : 1577781 / 16416279 or %9.61
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