

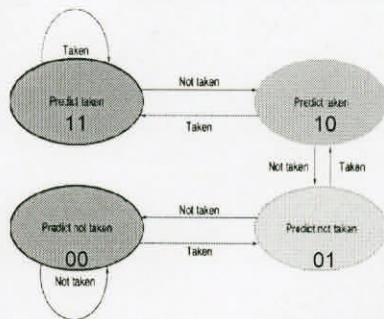
Problem 1

A branch is within a loop has the following repeating pattern (i.e. branch outcomes): T, NT, T, T, NT

- a) What is the accuracy of always-not-taken branch predictor?

2 out of 5 are predicted right. Thus, $2/5 = 40\%$

- b) What is the accuracy of the two-bit predictor (shown below) for the first five branches in this pattern, assuming the predictor starts off in the bottom left state 00 (predict not taken)?



The table below may be useful to calculate the accuracy.

Prediction	0 (NT)	01-NT	00-NT	01-NT	10-T
Actual Branch outcome	T	NT	T	T	NT
Right(1)/Wrong(0) Pred.	0	1	0	0	0
New Prediction	1 (NT)	00-NT	01-NT	10-T	01-NT

$1/5 = 20\%$

- c) What is the accuracy if this patter is repeated "forever"? (In the table below please begin with the last prediction from (b))

Prediction	01-NT	10-T	01-NT	10-T	11-T	10-T	11-T	10-T	11-T	11-T	10-T	11-T	10-T	11-T	11-T
Actual Branch	T	NT	T	T	NT	T	NT	T	T	NT	T	NT	T	T	NT
Right/Wrong	0	0	0	1	0	1	0	1	1	0	1	0	1	1	0
New Prediction	10-T	01-NT	10-T	11-T	10-T	11-T	10-T	11-T	11-T	10-T	11-T	10-T	11-T	11-T	10-T

After the second iteration the prediction and accuracy patterns are the same. There are three right predictions out of five. Thus, the accuracy is: $3/5 = 60\%$

Problem 2

A benchmark in a five-stage pipelined processor that uses a branch target buffer has the following characteristics:

- 31% ALU instructions,
- 26% Load instructions (assume no hazards with loads for this problem)
- 14% Store instructions
- 21% Branch instructions (62% of these branches are taken).
- 8% Jump instructions

A branch target buffer for conditional branch and jump instructions has the following features. Branch and jump instructions are found in the buffer (hit rate) 89% of the time. 92% of the time the prediction of the buffer is right (accuracy); thus, there is no penalty. Addresses for both branch and jump instructions are known at the end of the ID stage.

Please determine the CPI (cycles per instruction) for this machine.

Hint. Consider penalties/stalls due to:

1. BTB misprediction (when a branch is found in BTB but its prediction is wrong) and
2. BTB miss (when branch/jump is not found in BTB and is taken).

21%	Branch	89%	in BTB	92%	Right	0
				8%	Wrong	1
		11%	Not in BTB	38%	NT	0
				62%	T	1
8%	Jump	89%	in BTB	92%	Right	0
				8%	Wrong	1
		11%	Not in BTB	100% T		1

$$CPI = CPI_{ideal} + Stalls$$

$$CPI = 1 + \underbrace{0.21 \times (0.89 \times 0.08 \times 1 + 0.11 \times 0.62 \times 1)}_{\text{Branch stalls}} + \underbrace{.08 \times (0.89 \times 0.08 \times 1 + 0.11 \times 1)}_{\text{Jump stalls}}$$

$$CPI = 1.04377$$

If you consider that when a JUMP instructions is found in BTB is always right then the CPI will be:

[This assumption is not completely right, there jump on register (such as procedure/function returns) that are not always to the same place. In this case the BTB provides the wrong address.]

21%	Branch	89%	in BTB	92%	Right	0
				8%	Wrong	1
		11%	Not in BTB	38%	NT	0
				62%	T	1
8%	Jump	89%	in BTB	100%	Right	0
				100%	T	1
		11%	Not in BTB	100% T		1

$$CPI = 1 + 0.21 \times (0.89 \times 0.08 \times 1 + 0.11 \times 0.62 \times 1) + .08 \times (0.11 \times 1)$$

$$CPI = 1.038074$$