Handwritten

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4.28

4.28.1

	cycle 1	cycle 2	cycle 3	cycle 4	cycle 5	cycle 6	cycle 7
pc (branch)	IF	ID	EX	MEM	WB		
pc+x (taken)		IF	ID				
pc+4 (not taken)			IF	ID	EX	MEM	WB

When prediction misses, It takes an extra cycle. CPI:

$$0.25 \times (0.45 \times 1 + 0.55 \times 2) + 0.75 \times 1 = 1.1375$$

4.28.2

CPI:

$$0.25 \times (0.55 \times 1 + 0.45 \times 2) + 0.75 \times 1 = 1.1125$$

4.28.3

CPI:

$$0.25 \times (0.85 \times 1 + 0.15 \times 2) + 0.75 \times 1 = 1.0375$$

4.28.4

After conversion, frequency of branch instructions is 12.5%, and prediction accuracy remains the same.

New CPI:

$$0.125 \times (0.85 \times 1 + 0.15 \times 2) + 0.875 \times 1 = 1.01875$$

Speedup:

$$\frac{\text{Execution Time}_{\text{old}}}{\text{Execution Time}_{\text{new}}} = \frac{\text{CPI}_{\text{old}}}{\text{CPI}_{\text{new}}} = \frac{1.0375}{1.01875} \approx 1.018 = 101.8\%$$

4.28.5

After conversion, number of instructions is $100\% + 12.5\% = 112.5\%$, frequency of branch is $\frac{12.5\%}{112.5\%} = 11.1\%$, and prediction accuracy remains the same.

New CPI:

$$0.111 \times (0.85 \times 1 + 0.15 \times 2) + 0.889 \times 1 = 1.01665$$

Speedup:

$$\begin{aligned}\frac{\text{Execution Time}_{\text{old}}}{\text{Execution Time}_{\text{new}}} &= \frac{\text{CPI}_{\text{old}}}{\text{CPI}_{\text{new}}} \times \frac{\#\text{ Instructions}_{\text{old}}}{\#\text{ Instructions}_{\text{new}}} \\ &= \frac{1.0375}{1.01665} \times \frac{1}{1.125} \\ &\approx 0.907 \\ &= 90.7\%\end{aligned}$$

4.28.6

Assume the accuracy on the remaining 20 is p.

$$\begin{aligned}0.8 \times 1 + 0.2 \times p &= 0.85 \\ \Rightarrow p &= \frac{0.05}{0.2} \\ &= 0.25\end{aligned}$$

4.29

4.29.1

Always-taken accuracy: $\frac{3}{5} = 60\%$.

Always-not-taken accuracy: $\frac{2}{5} = 40\%$.

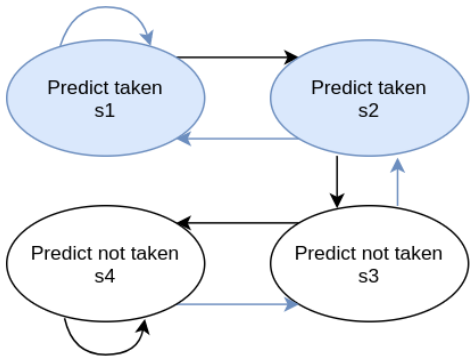
4.29.2

Branch number	Prediction	Outcome	Correctness	Next prediction
1	NT	T	X	NT
2	NT	NT	O	NT
3	NT	T	X	NT
4	NT	T	X	T

Accuracy: $\frac{1}{4} = 25\%$

4.29.3

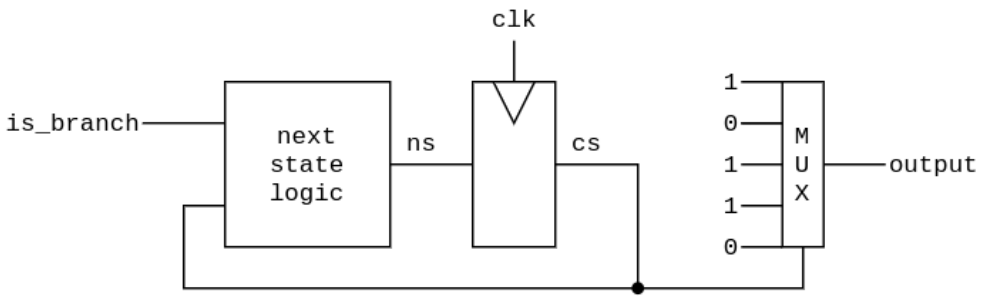
Define the state of predictor as this figure:



Branch number	Current state	Outcome	Next state	Correctness
1	**s4**	T	s3	X
2	s3	NT	s4	O
3	s4	T	s3	X
4	s3	T	s2	X
5	s2	NT	**s3**	X
6	**s3**	T	s2	X
7	s2	NT	s3	X
8	s3	T	s2	X
9	s2	T	s1	O
10	s1	NT	**s2**	X
11	**s2**	T	s1	O
12	s1	NT	s2	X
13	s1	T	s1	O
14	s1	T	s1	O
15	s1	NT	**s2**	X

The predictor enters a loop at 11-th branch. In this loop, the accuracy is $\frac{3}{5} = 60\%$. As the pattern repeats forever, the total accuracy approaches 60%.

4.29.4



`next state logic` works like this:

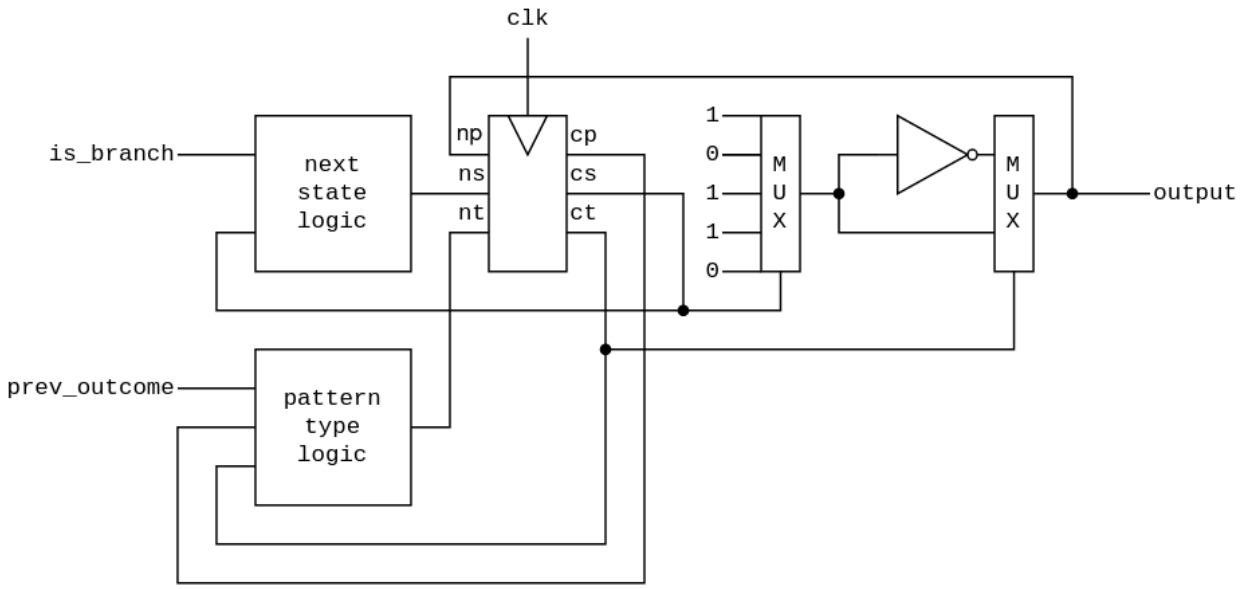
```
if (is_branch)
    ns = (cs+1)%5
else
    ns = cs
```

Then `cs` is used to control a multiplexer, which determines the output.

4.29.5

The accuracy would be 0.

4.29.6



`next state logic` works the same as 4.29.4.

`pattern type logic` works like this:

```
if (cp != prev_outcome)
    nt = ~ct
else
    nt = ct
```

`ct` is used to indicate which type of pattern is given.