BRANCH PREDICTORS

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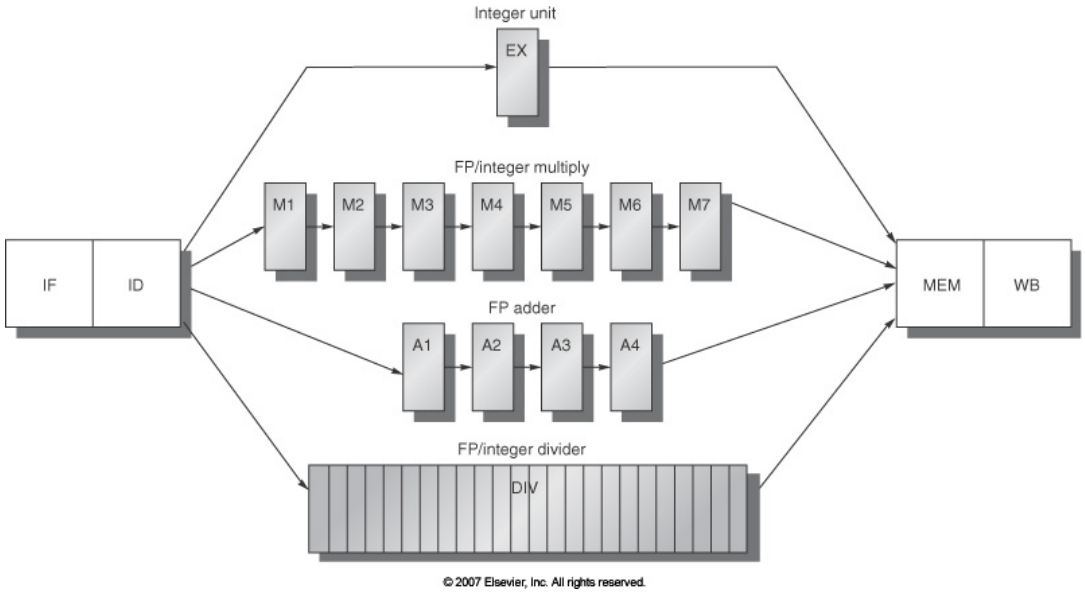
Overview

- Announcements
  - Homework 2 submission deadline: Feb. 13th
  - Homework 3 release: Feb. 14th

- This lecture
  - Dynamic branch prediction
  - Counter based branch predictor
  - Correlating branch predictor
  - Global vs. local branch predictors

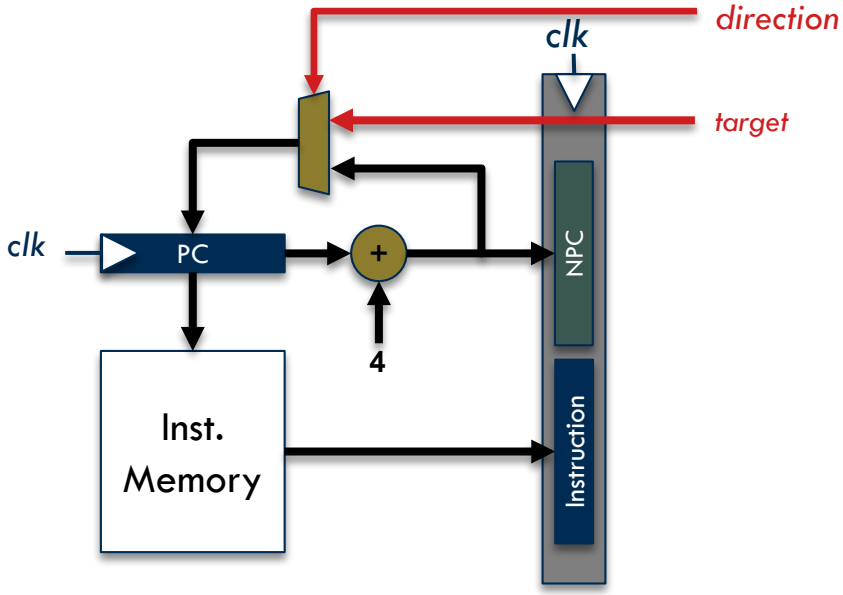
Big Picture: Why Branch Prediction?

- Problem: performance is mainly limited by the number of instructions fetched per second
- Solution: deeper and wider frontend
- Challenge: handling branch instructions



Big Picture: How to Predict Branch?

- Static prediction (based on direction or profile)
  - Always not-taken
    - Target = next PC
  - Always taken
    - Target = unknown
- Dynamic prediction
  - Special hardware using PC



Recall: Dynamic Branch Prediction

- Hardware unit capable of learning at runtime
  - 1. Prediction logic
    - Direction (taken or not-taken)
    - Target address (where to fetch next)
  - 2. Outcome validation and training
    - Outcome is computed regardless of prediction
  - 3. Recovery from misprediction
    - Nullify the effect of instructions on the wrong path

Branch Prediction

- Goal: avoiding stall cycles caused by branches
- Solution: static or dynamic branch predictor
  - 1. prediction
  - 2. validation and training
  - 3. recovery from misprediction
- Performance is influenced by the frequency of branches (b), prediction accuracy (a), and misprediction cost (c)

$$Speedup = \frac{Old\ Time}{New\ Time} = \frac{CPI_{old}}{CPI_{new}} = \frac{1 + bc}{1 + (1 - a)bc}$$

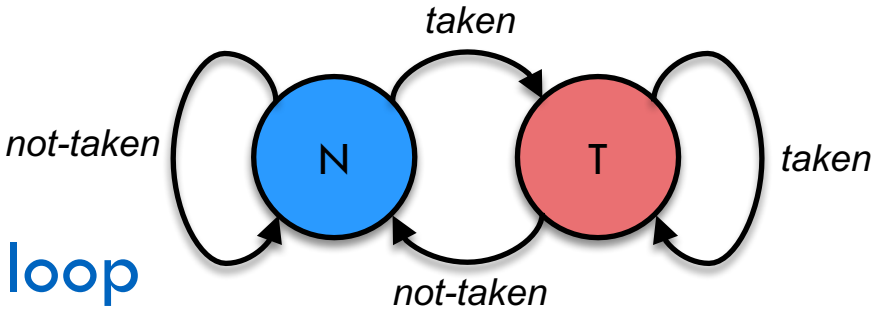
Problem

- A pipelined processor requires 3 stall cycles to compute the outcome of every branch before fetching next instruction; due to perfect forwarding/bypassing, no stall cycles are required for data/structural hazards; every 5^{th} instruction is a branch.
  - Compute speedup gained by a branch predictor with 90% accuracy

$$\text{Speedup} = (1 + 0.2 \times 3) / (1 + 0.1 \times 0.2 \times 3) = 1.5$$

Bimodal Branch Predictors

- One-bit branch predictor
  - Keep track of and use the outcome of last branch
- Shared predictor
- Two mispredictions per loop



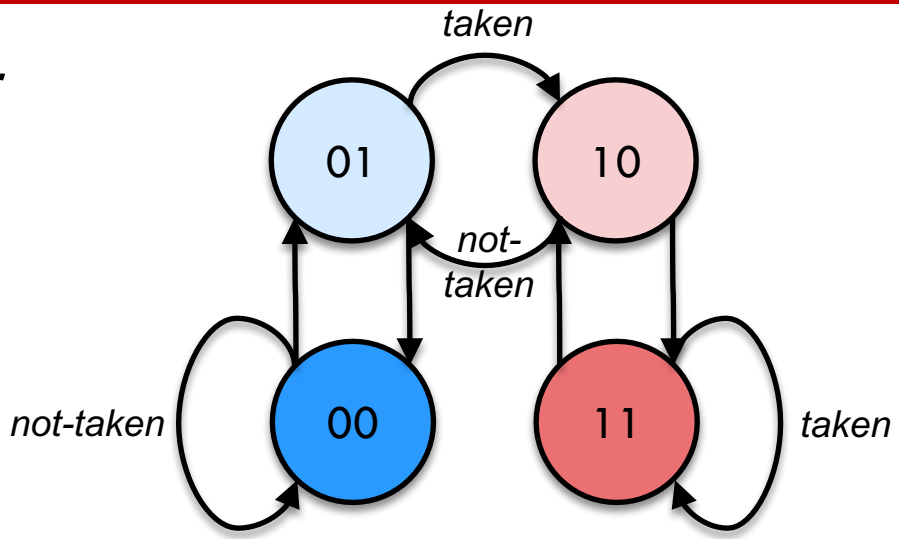
Accuracy = 26/30 = 0.86

How to improve?

```
while(1) {
    for(i=0; i<10; i++) {        branch-1
    }
    for(j=0; j<20; j++) {        branch-2
    }
}
```

Bimodal Branch Predictors

- Two-bit branch predictor
  - Increment if taken
  - Decrement if untaken

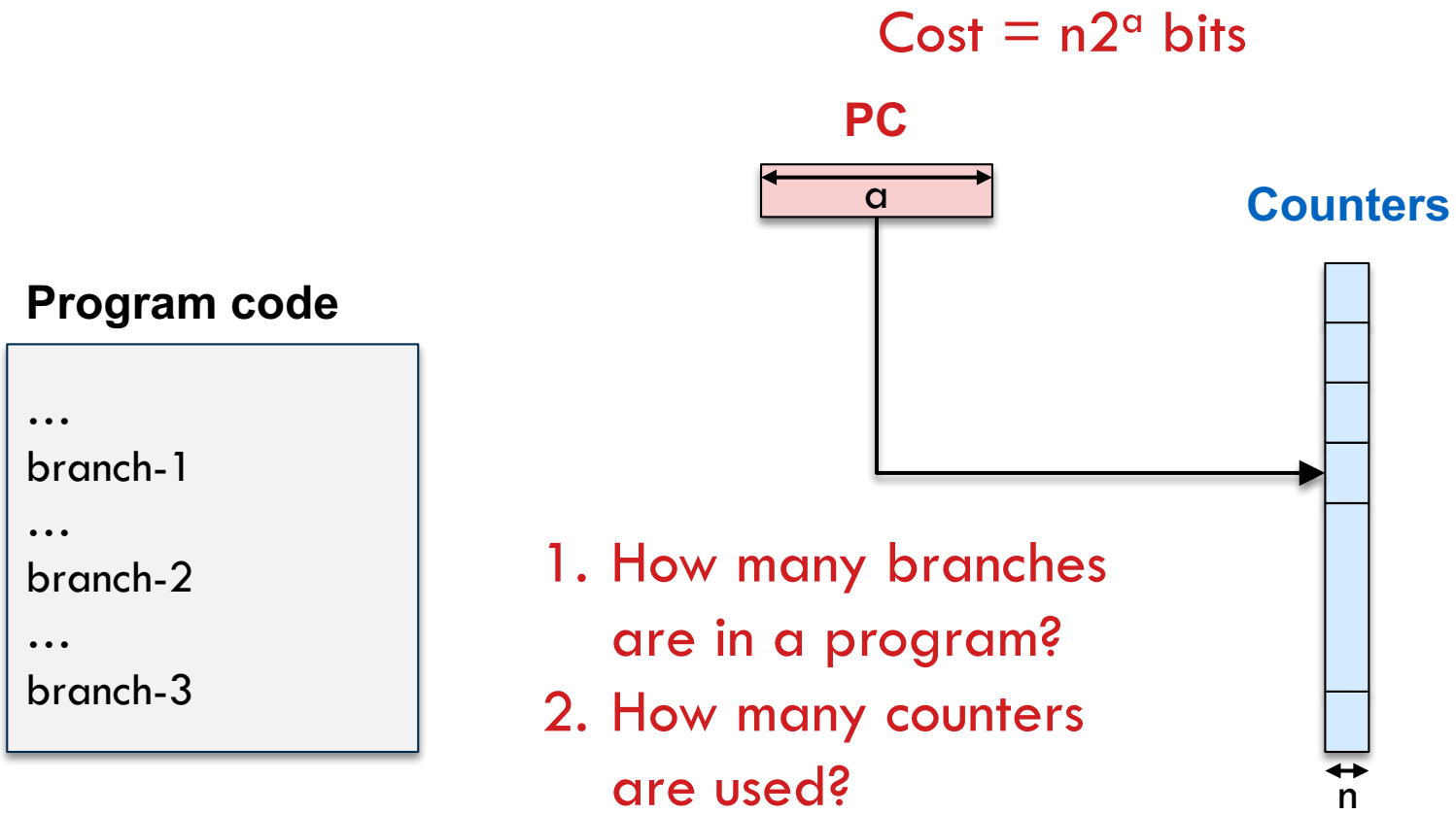


- One misprediction on loop exit
- Accuracy = 28/30 = 0.93
- **How to improve?**
  - 3-bit predictor?
- **Problem?**
  - A single predictor shared among many branches

```
while(1) {
    for(i=0; i<10; i++) {        branch-1
    }
    for(j=0; j<20; j++) {        branch-2
    }
}
```

Using Multiple Counters

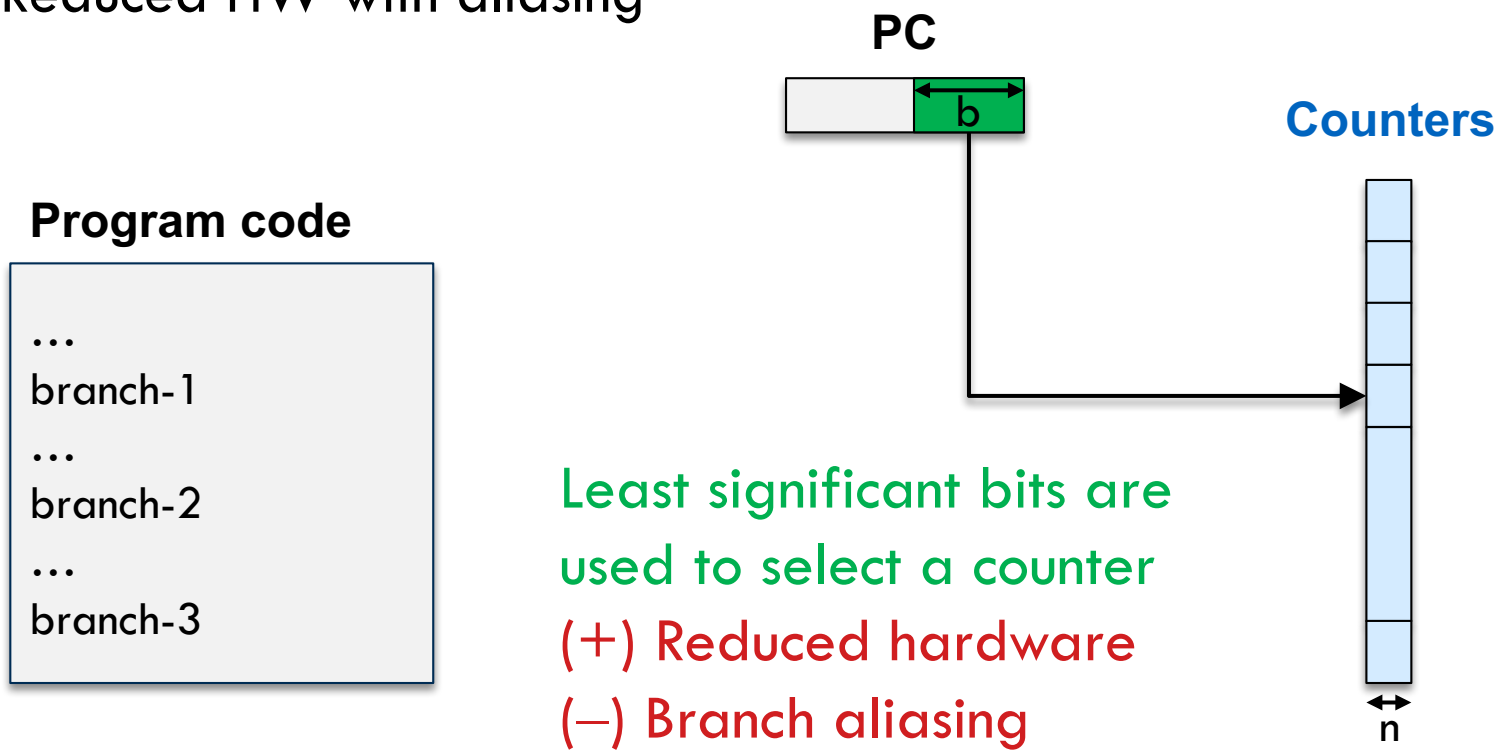
- How to assign a branch to each counter?



Using Multiple Counters

- How to assign a branch to each counter?
  - Decode History Table (DHT)
    - Reduced HW with aliasing

Cost = $n2^b$ bits



Least significant bits are used to select a counter

(+) Reduced hardware

(–) Branch aliasing

Using Multiple Counters

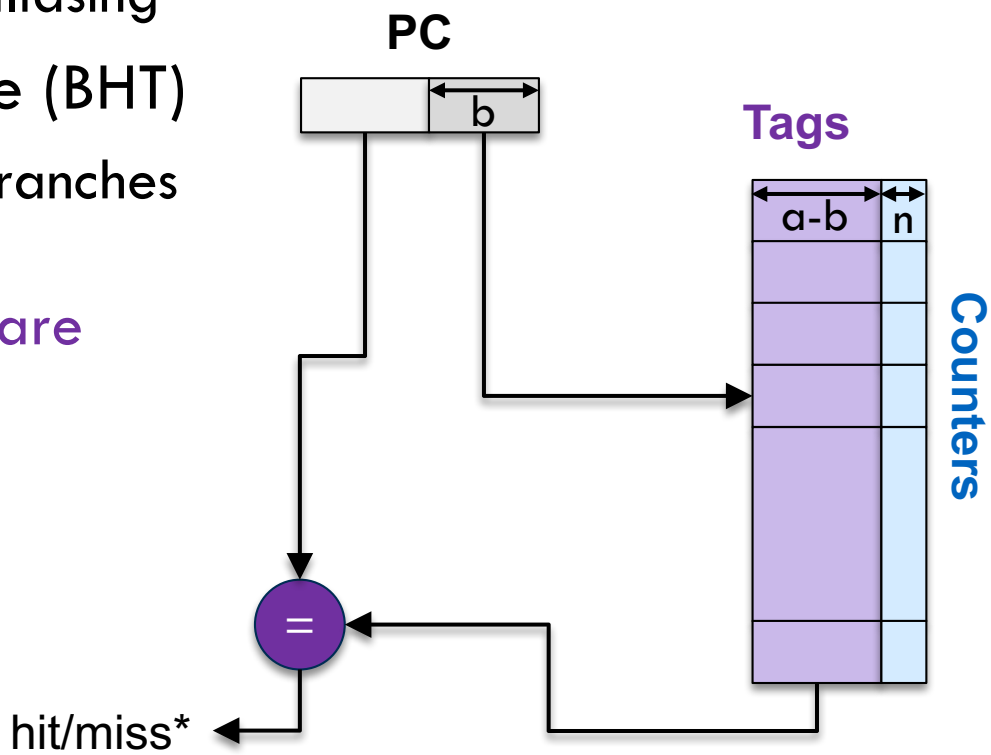
- How to assign a branch to each counter?
  - Decode History Table (DHT)
    - Reduced HW with aliasing
  - Branch History Table (BHT)
    - Precisely tracking branches

Most significant bits are used as tags

(+) No aliasing

(–) Missing entries

Cost = $(a-b+n)2^b$ bits

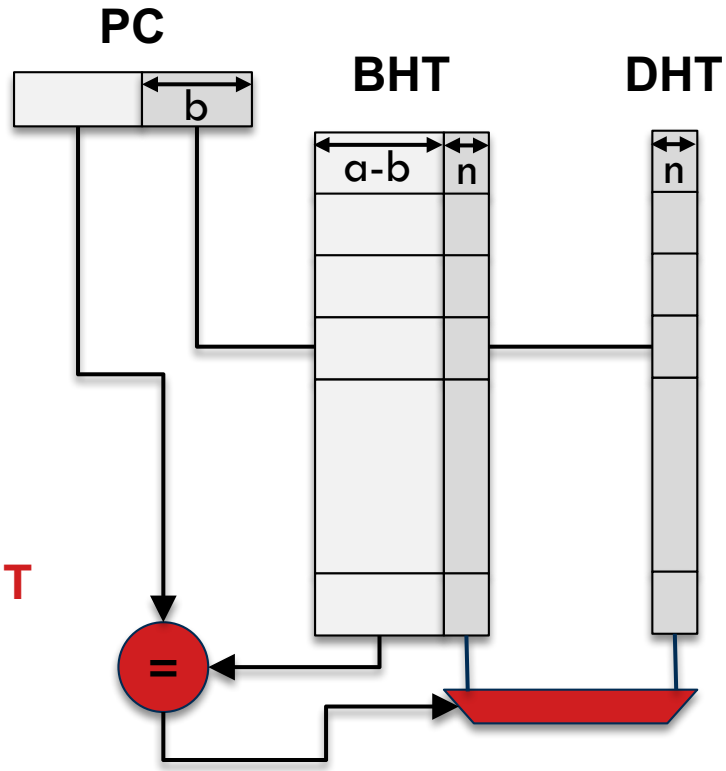


Using Multiple Counters

- How to assign a branch to each counter?
  - Decode History Table (DHT)
    - Reduced HW with aliasing
  - Branch History Table (BHT)
    - Precisely tracking branches
  - Combined BHT and DHT
    - BHT is used on a hit
    - DHT is used/updated on a miss

DHT typically has more entries than BHT

Cost = $(a-b+2n)2^b$ bits



Correlating Branch Predictor

- Executed branches of a program stream may be correlated

```
while (1) {
  if(x == 0)
     y = 0;
    …
  if(y == 0)
     x = 1;
}
```

branch-1

branch-2

```
while:
        BNEQ R1, R0, skp1
        ADDI  R2, R0, #0
skp1:  …
        BNEQ R2, R0, skp2
        ADDI  R1, R0, #1
skp2:  J while
```

Correlating Branch Predictor

- Executed branches of a program stream may be correlated

```
while (1) {
  if(x == 0)
     y = 0;
   ...
  if(y == 0)
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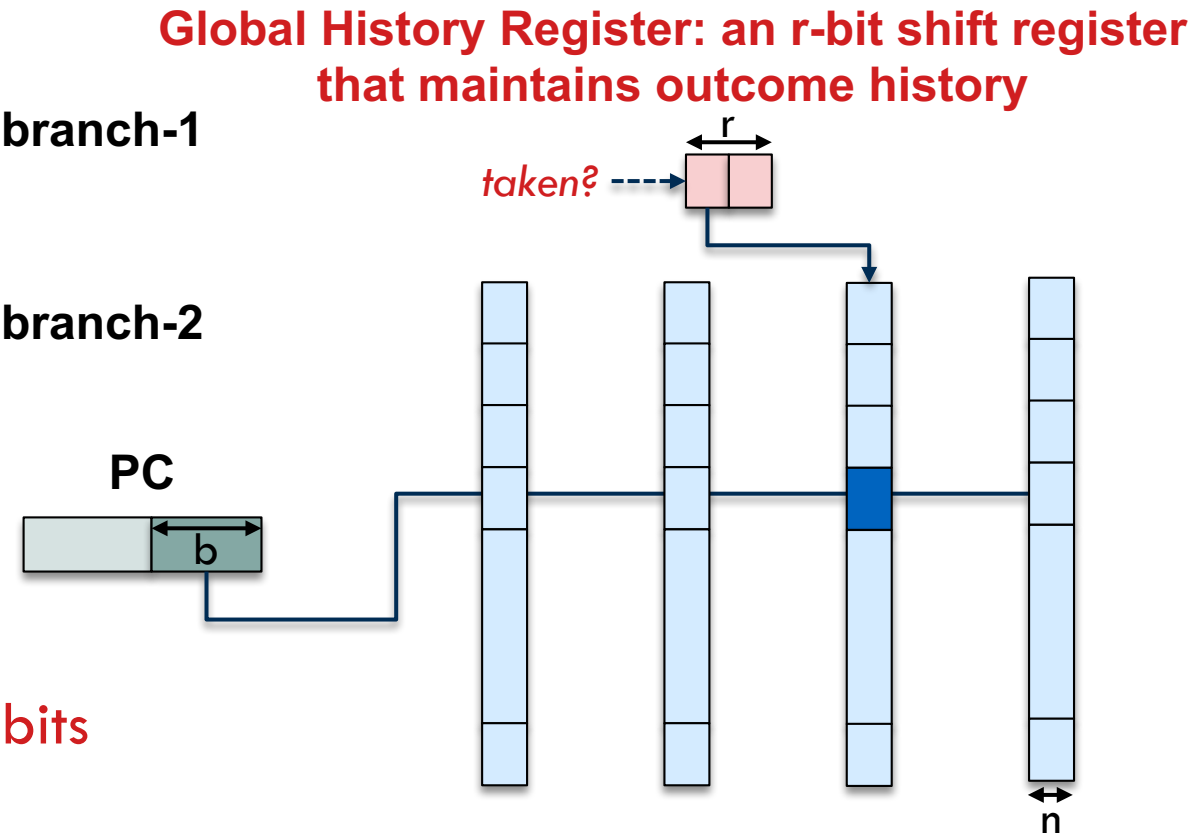
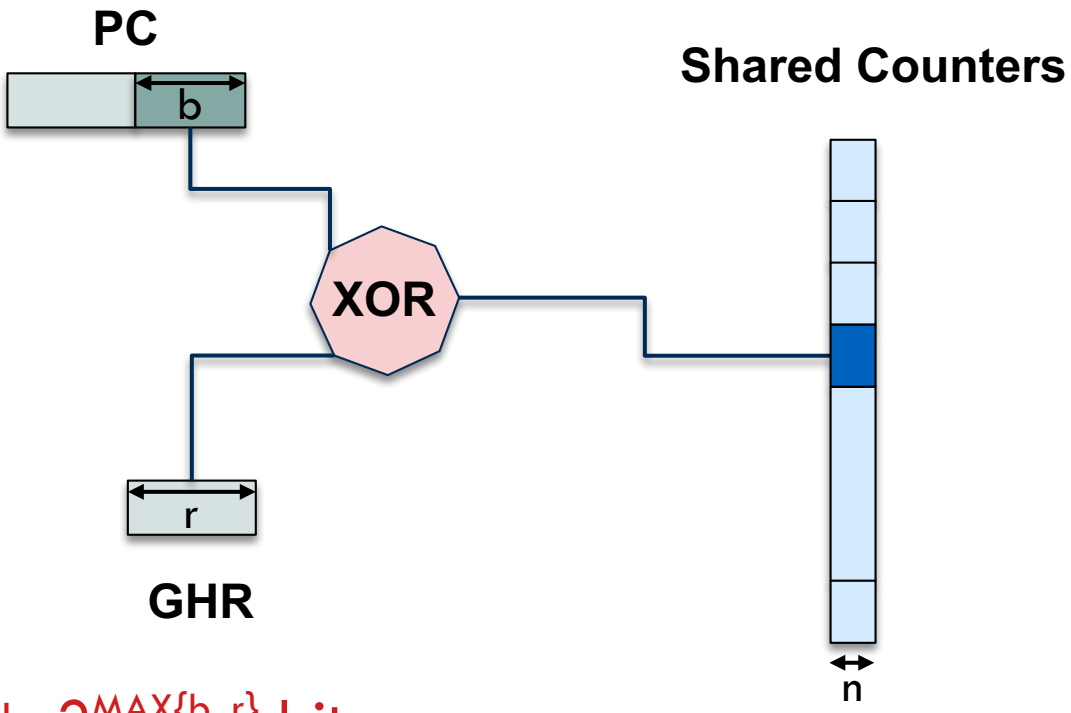


Cost = $r+n2^{b+r}$ bits

Global Branch Predictor

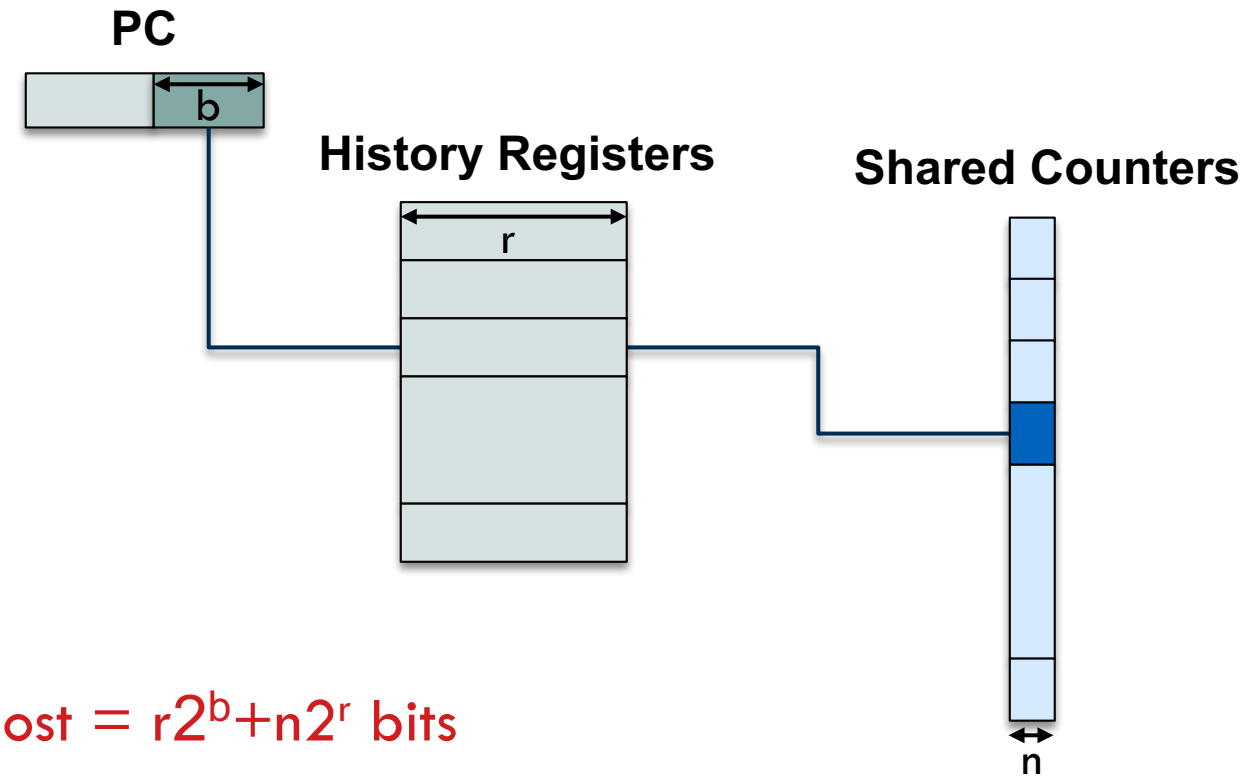
- GHR is merged with PC bits to choose a counter



Cost = $r+n2^{MAX\{b, r\}}$ bits

Local Branch Predictor

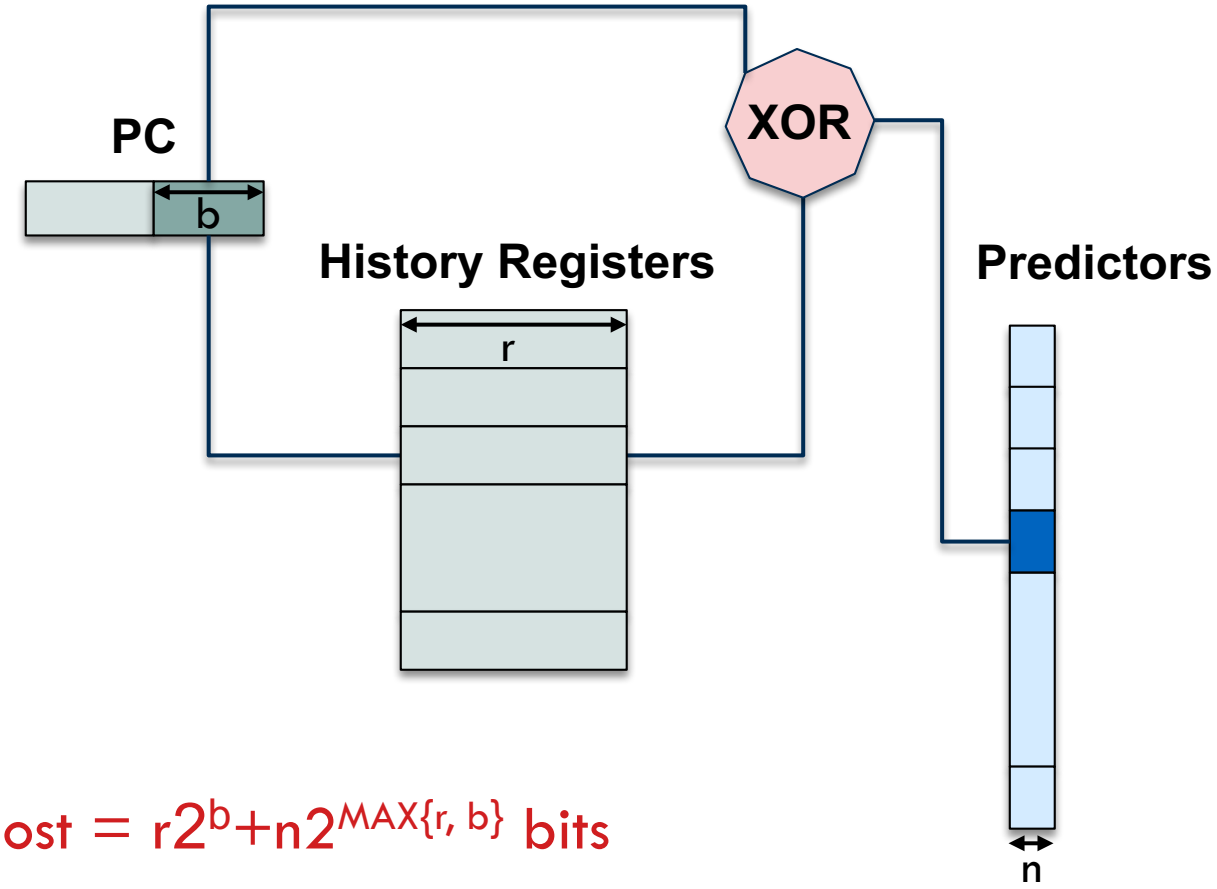
- One GHR per branch



Cost = $r2^b+n2^r$ bits

Local Branch Predictor

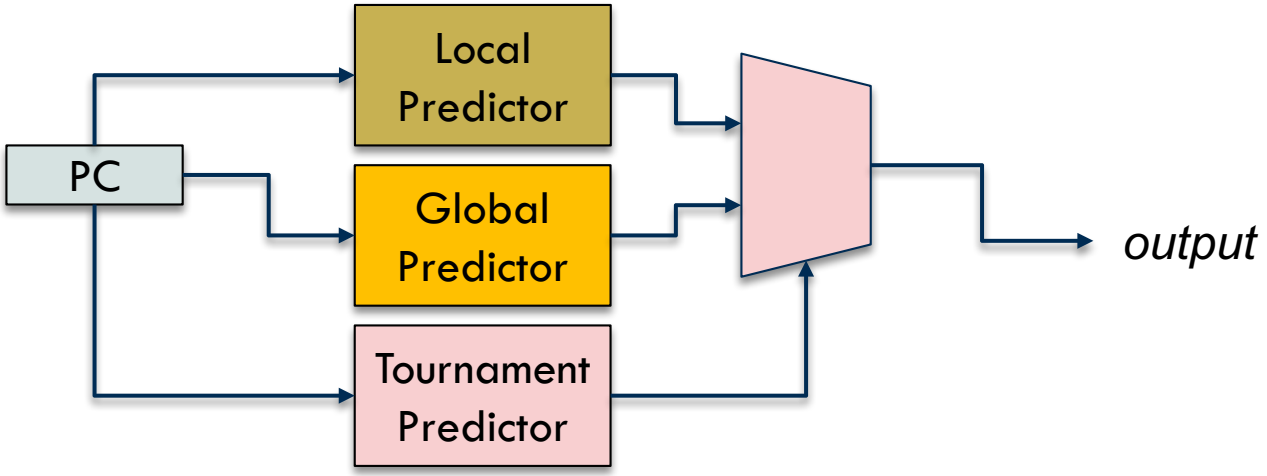
- One GHR per branch



Cost = $r2^b+n2^{MAX\{r, b\}}$ bits

Tournament Branch Predictor

- Local predictor may work well for some applications, while global predictor works well for some other programs
  - Include both and identify/use the best one for each branch



Two bit saturating counters

Branch Prediction Summary

- Dedicated predictor per branch
  - Program counter is used for assigning predictors to branches
- Capturing correlation among branches
  - Shift register is used to track history
- Predicting branch direction is not enough
  - Which instruction to be fetched if taken?
- Storing the target instruction can eliminate fetching
  - Extra hardware is required

Branch Target Buffer

- Store tags and target addresses for each branch