Lecture: Branch Prediction

- Topics: power/energy basics and DFS/DVFS,
  branch prediction, bimodal/global/local/tournament
  predictors, branch target buffer (Section 3.3,
  notes on class webpage)

Power Consumption Trends

- Dyn power α activity x capacitance x voltage^2 x frequency

- Capacitance per transistor and voltage are decreasing, but number of transistors is increasing at a faster rate; hence clock frequency must be kept steady

- Leakage power is also rising; is a function of transistor count, leakage current, and supply voltage

- Power consumption is already between 100-150W in high-performance processors today

- Energy = power x time = (dynpower + lkgpower) x time

Power Vs. Energy

- Energy is the ultimate metric: it tells us the true "cost" of performing a fixed task
- Power (energy/time) poses constraints; can only work fast enough to max out the power delivery or cooling solution
- If processor A consumes 1.2x the power of processor B, but finishes the task in 30% less time, its relative energy is 1.2 X 0.7 = 0.84; Proc-A is better, assuming that 1.2x power can be supported by the system

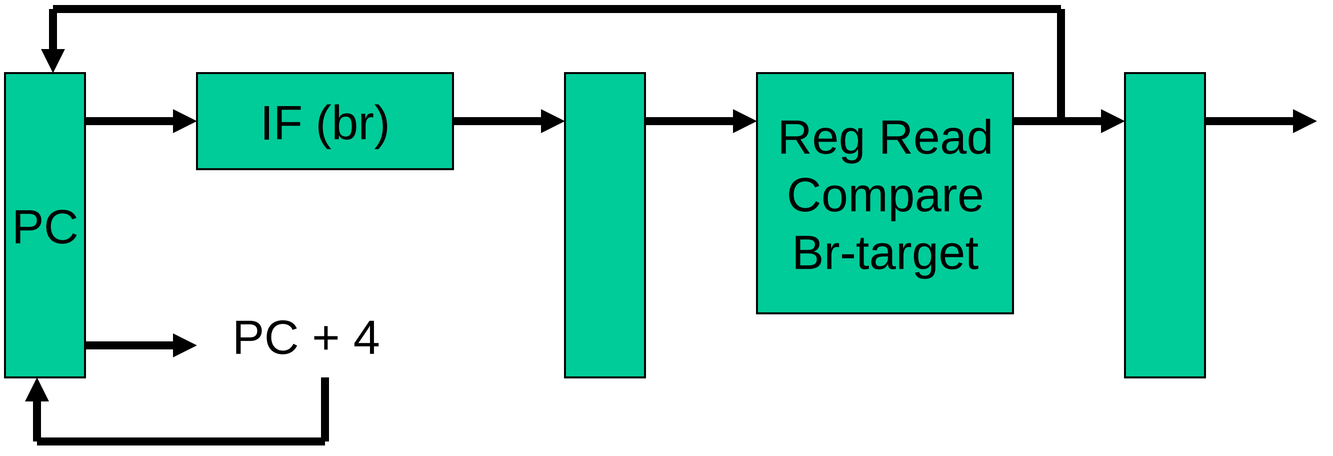
Reducing Power and Energy

- Can gate off transistors that are inactive (reduces leakage)
- Design for typical case and throttle down when activity exceeds a threshold
- DFS: Dynamic frequency scaling -- only reduces frequency and dynamic power, but hurts energy
- DVFS: Dynamic voltage and frequency scaling – can reduce voltage and frequency by (say) 10%; can slow a program by (say) 8%, but reduce dynamic power by 27%, reduce total power by (say) 23%, reduce total energy by 17%
(Note: voltage drop → slow transistor → freq drop)

DFS and DVFS

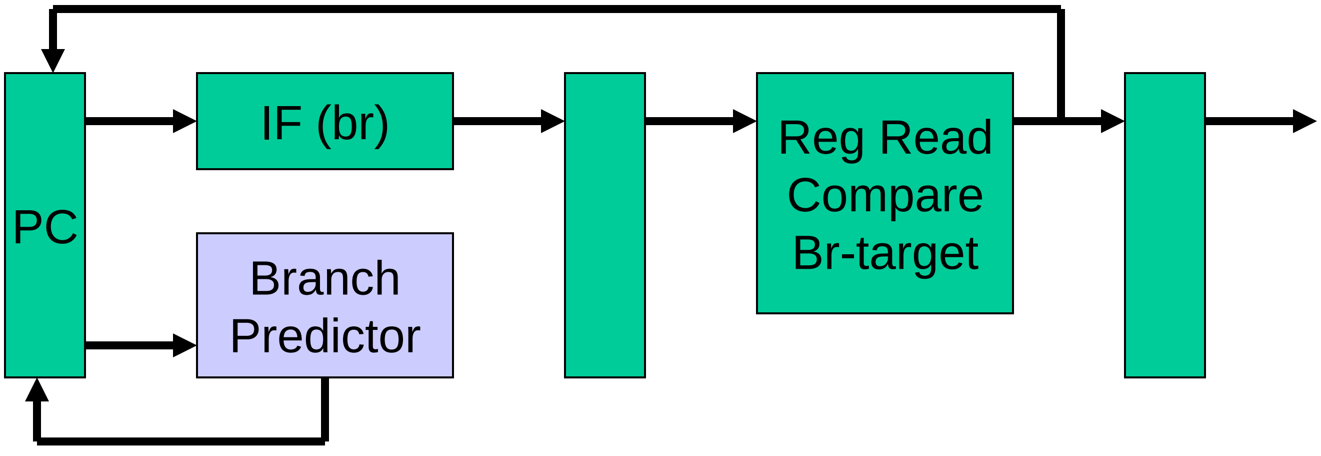
- DFS
- DVFS

Pipeline without Branch Predictor



In the 5-stage pipeline, a branch completes in two cycles →
If the branch went the wrong way, one incorrect instr is fetched →
One stall cycle per incorrect branch

Pipeline with Branch Predictor



In the 5-stage pipeline, a branch completes in two cycles →
If the branch went the wrong way, one incorrect instr is fetched →
One stall cycle per incorrect branch

1-Bit Bimodal Prediction

- For each branch, keep track of what happened last time and use that outcome as the prediction
- What are prediction accuracies for branches 1 and 2 below:

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

2-Bit Bimodal Prediction

- For each branch, maintain a 2-bit saturating counter:
  if the branch is taken: counter = min(3,counter+1)
  if the branch is not taken: counter = max(0,counter-1)

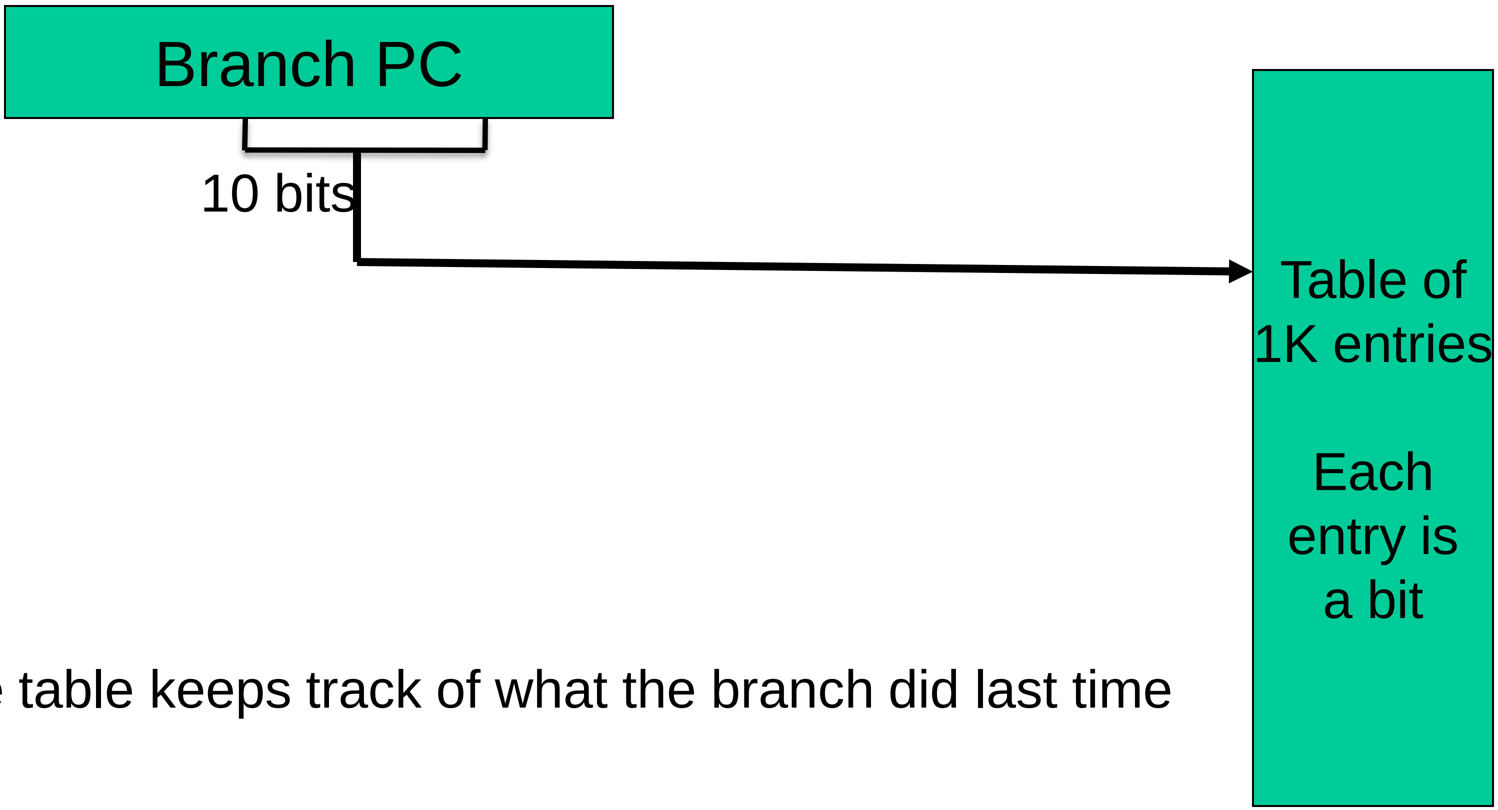
- If (counter >= 2), predict taken, else predict not taken

- Advantage: a few atypical branches will not influence the prediction (a better measure of “the common case”)

- Especially useful when multiple branches share the same counter (some bits of the branch PC are used to index into the branch predictor)

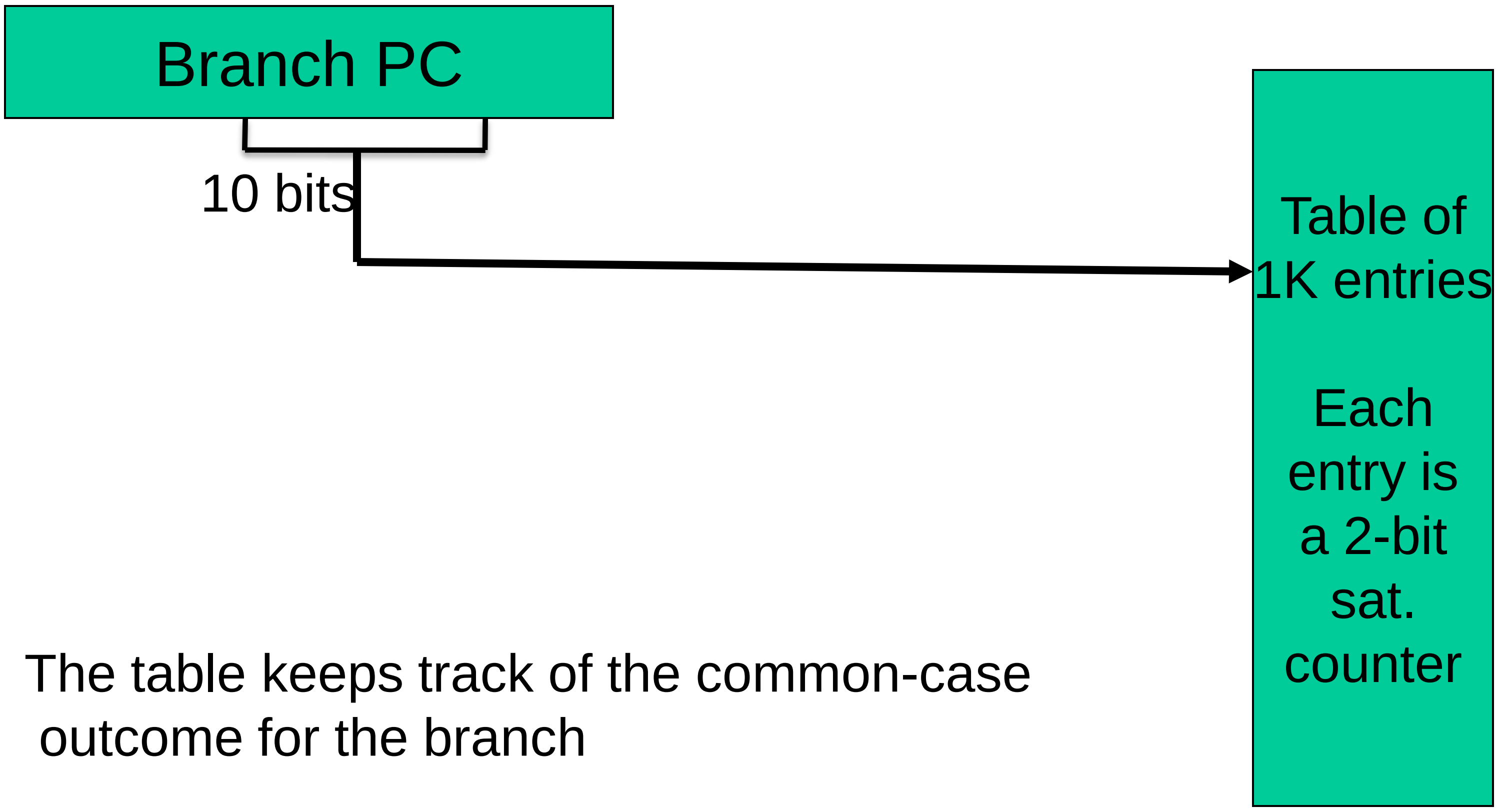
- Can be easily extended to N-bits (in most processors, N=2)

Bimodal 1-Bit Predictor



The table keeps track of what the branch did last time

Bimodal 2-Bit Predictor



The table keeps track of the common-case outcome for the branch

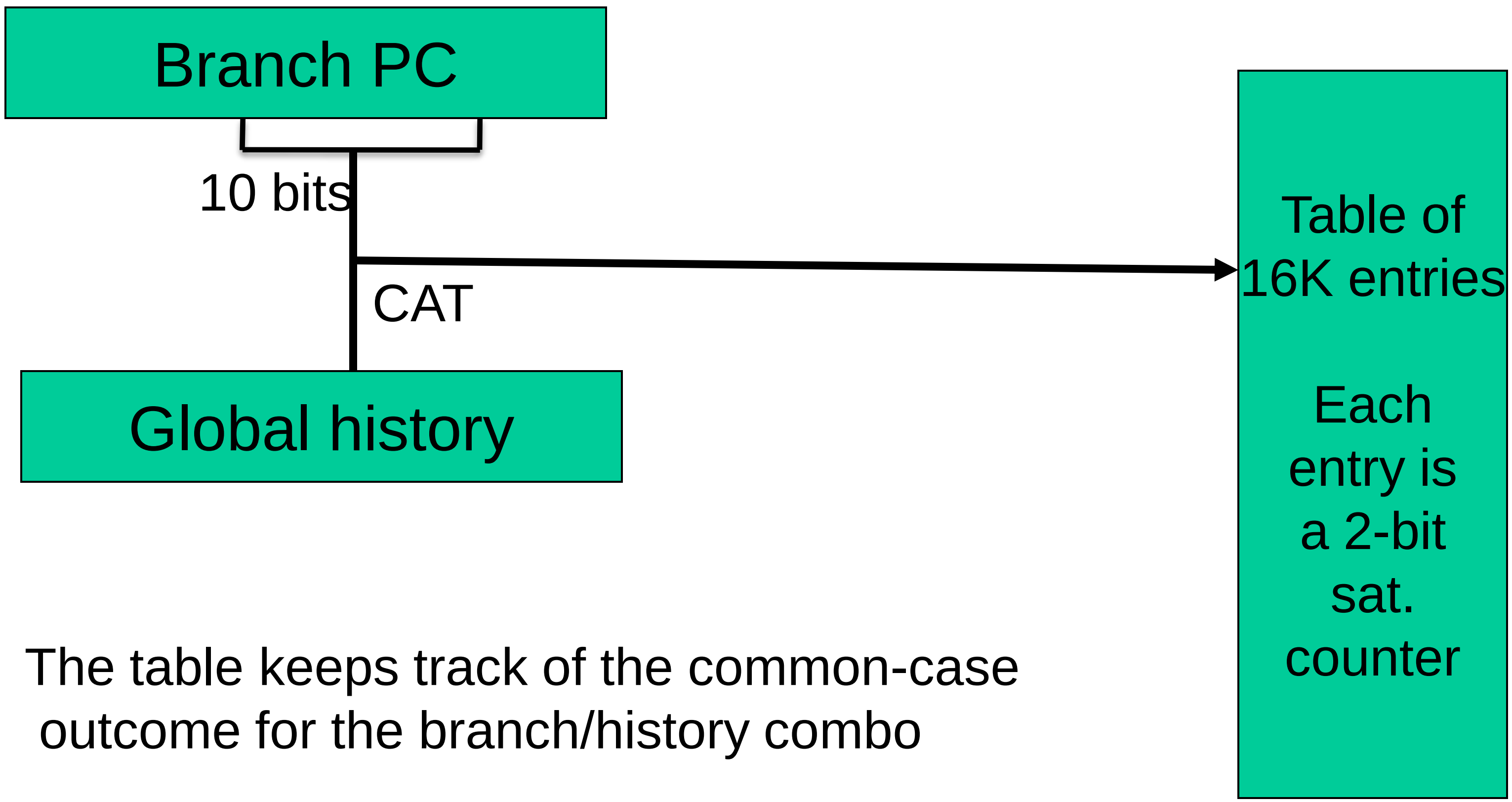
Correlating Predictors

- Basic branch prediction: maintain a 2-bit saturating counter for each entry (or use 10 branch PC bits to index into one of 1024 counters) – captures the recent "common case" for each branch

- Can we take advantage of additional information?
  - If a branch recently went 01111, expect 0; if it recently went 11101, expect 1; can we have a separate counter for each case?
  - If the previous branches went 01, expect 0; if the previous branches went 11, expect 1; can we have a separate counter for each case?

Hence, build correlating predictors

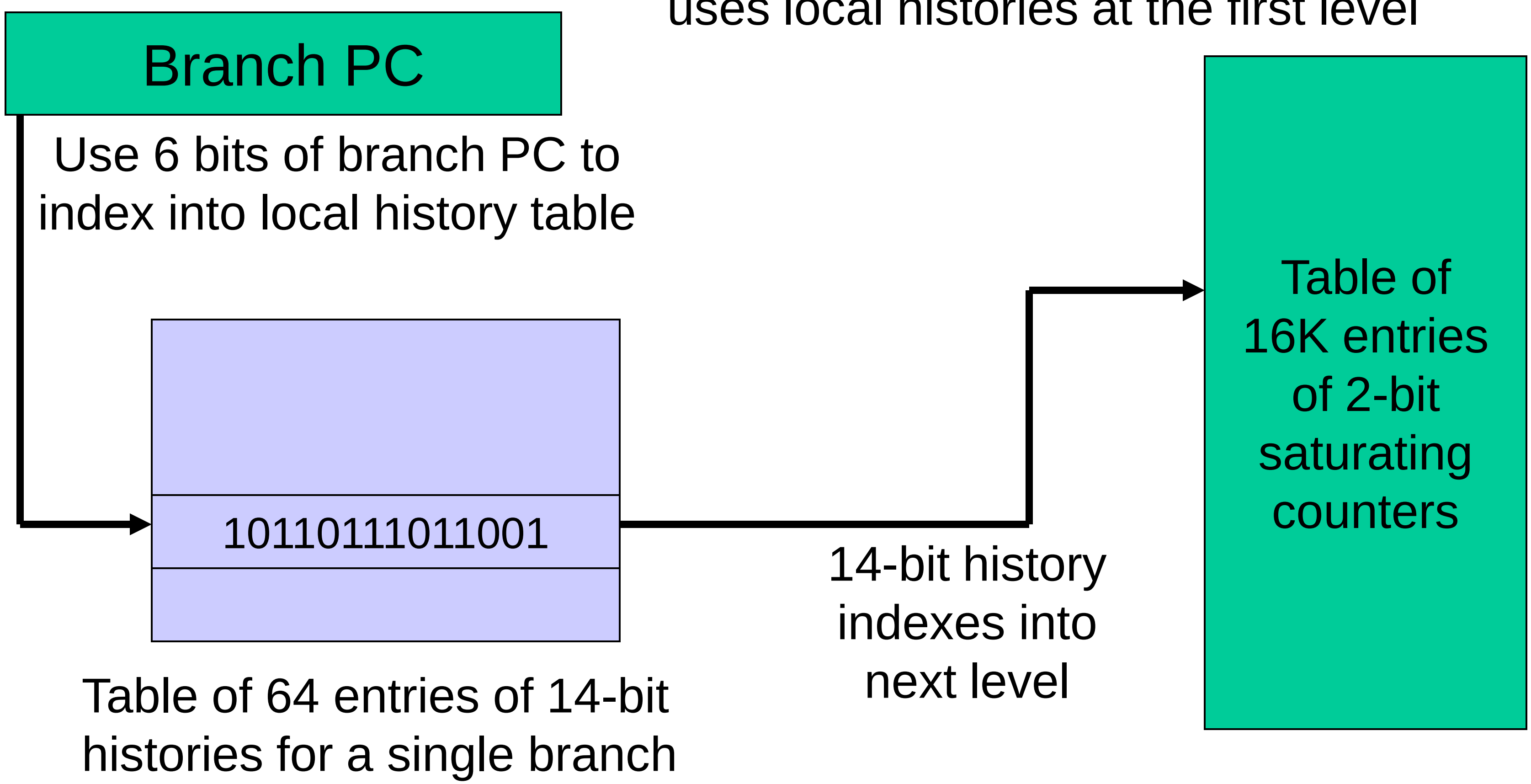
Global Predictor



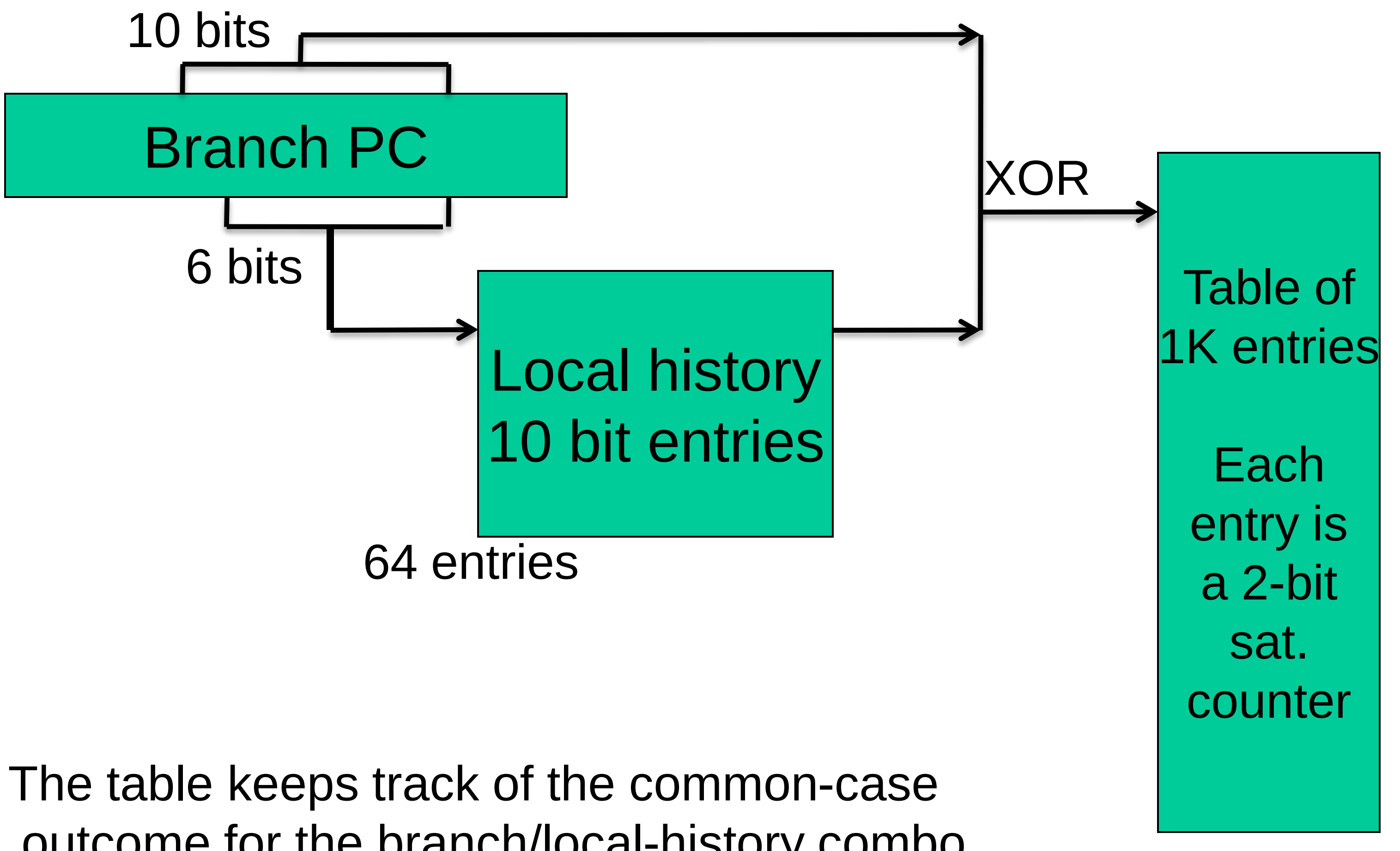
The table keeps track of the common-case outcome for the branch/history combo

Local Predictor

Also a two-level predictor that only uses local histories at the first level



Local Predictor



The table keeps track of the common-case outcome for the branch/local-history combo

Local/Global Predictors

- Instead of maintaining a counter for each branch to capture the common case,

→ Maintain a counter for each branch and surrounding pattern
→ If the surrounding pattern belongs to the branch being predicted, the predictor is referred to as a local predictor
→ If the surrounding pattern includes neighboring branches, the predictor is referred to as a global predictor

Tournament Predictors

- A local predictor might work well for some branches or programs, while a global predictor might work well for others

- Provide one of each and maintain another predictor to identify which predictor is best for each branch

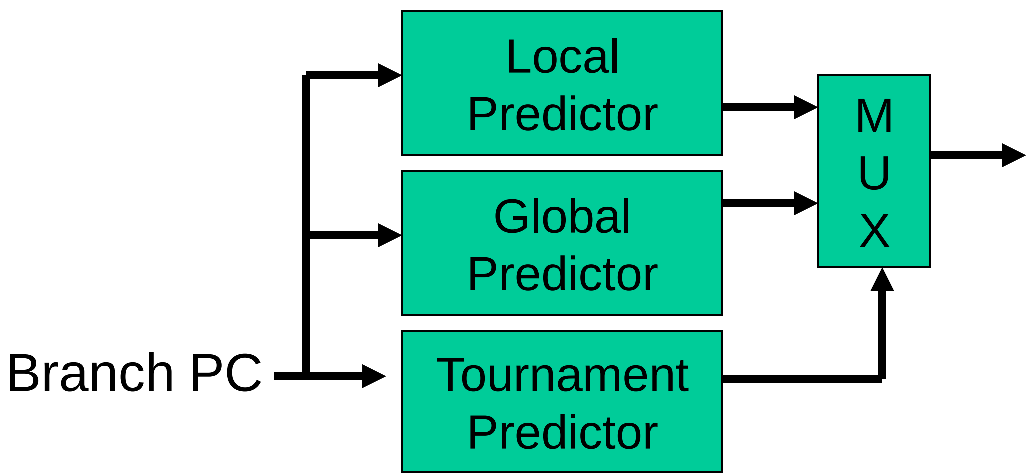


Table of 2-bit saturating counters

Alpha 21264:
1K entries in level-1
1K entries in level-2

4K entries
12-bit global history

4K entries

Total capacity: ?

Branch Target Prediction

- In addition to predicting the branch direction, we must also predict the branch target address
- Branch PC indexes into a predictor table; indirect branches might be problematic
- Most common indirect branch: return from a procedure – can be easily handled with a stack of return addresses

Title

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