Chapter 9: Advanced Instruction Flow
Modern Processor Design: Fundamentals of Superscalar Processors

Advanced Branch Prediction
- Control Flow Speculation
  - Branch Speculation
  - Mis-speculation Recovery
- Two-Level Adaptive Branch Prediction
- Global BHSR Scheme (GAs)
- Per-Branch BHSR Scheme (PAs)
- Gshare Branch Predictor
- Combining branch predictor
- Perceptron branch predictor

Branch Speculation
- Leading Speculation
  - Typically done during the Fetch stage
  - Based on potential branch instruction(s) in the current fetch group
- Trailing Confirmation
  - Typically done during the Branch Execute stage
  - Based on the next Branch instruction to finish execution

Branch Speculation
- Leading Speculation
  1. Tag speculative instructions
  2. Advance branch and following instructions
  3. Buffer addresses of speculated branch instructions
- Trailing Confirmation
  1. When branch resolves, remove/deallocate speculation tag
  2. Permit completion of branch and following instructions
**Branch Speculation**
- Start new correct path
  - Must remember the alternate (non-predicted) path
- Eliminate incorrect path
  - Must ensure that the mis-speculated instructions produce no side effects

**Mis-speculation Recovery**
- **Start new correct path**
  1. Update PC with computed branch target (if predicted NT)
  2. Update PC with sequential instruction address (if predicted T)
  3. Can begin speculation again at next branch
- **Eliminate incorrect path**
  1. Use tag(s) to deallocate ROB entries occupied by speculative instructions
  2. Invalidate all instructions in the decode and dispatch buffers, as well as those in reservation stations

**Tracking Instructions**
- Assign branch tags
  - Allocated in circular order
  - Instruction carries this tag throughout processor
- Track instruction groups
  - Instructions managed in groups, max. one branch per group
  - ROB structured as groups
    - Leads to some inefficiency
    - Simpler tracking of speculative instructions

**Program Control Flow**
Two-Level Adaptive Branch Prediction

- So far, the prediction of each static branch instruction is based solely on its own past behavior and independent of the behaviors of other neighboring static branch instructions (except for inadvertent aliasing).

Yeh & Patt Michigan Study, 1992

- **Two-level adaptive branch prediction:**
  - First level: History of last k branches encountered
  - Second level: branch behavior of the last s occurrences of the specific pattern of these k branches
  - Use a Branch History Register (BHR) in conjunction with a Pattern History Table (PHT)
  - Example: \(k=6, s=6\)
    - Last k branches with the behavior (11100101)
    - History at the entry \((11100101)\) is \([101010]\)
  - Using history, branch prediction algorithm predicts direction of the branch
  - Effectiveness:
    - Averaging 97% accuracy for SPEC
    - Used in the Intel P6 and AMD K6

Yeh & Patt Michigan Study, 1992

- **Global BHR Scheme (GAs):**
  - To achieve 97% average prediction accuracy:
    - (1) BHR: 18 bits; (1) PHT: \(2^9 \times 2\) bits
    - (512x6) BHR: 12 bits; (1) PHT: \(2^6 \times 2\) bits
    - (512x6) BHR: 6 bits; (512) PHT: \(2^6 \times 2\) bits
### Per-branch BHSR (PAs)

- Branch Address
- Branch History Shift Register (BHSR): $k \times 2^i$
- Prediction
- BHT of $2 \times 2^{j+k}$

### Gshare Branch Predictor

- Branch Address
- Branch History Shift Register (BHSR): $j$ bits
- Prediction
- BHT of $2 \times 2^{\max(j,k)}$

### Combining Branch Predictor

- Branch Address
- 2-level Branch Predictor (e.g., gshare)
- Simple Branch Predictor (e.g., bimodal)
- Selector
- Prediction

### Perceptron Branch Prediction

[Jimenez, Lin HPCA 2001]

- Perceptron
  - Basis in AI concept [1962]
  - Computes boolean result based on multiple weighted inputs
- Adapted for branch prediction
  - $x_i$ from branch history (1 T, -1 NT)
  - $w_i$ incremented whenever branch outcome matches $x_i$
  - Finds correlation between current branch and prior branches

Mathematical formula:

$$y = w_0 + \sum_{i=1}^{n} x_i w_i$$

- $y$: Prediction
- $w_0$: Bias
- $x_i$: Input
- $w_i$: Weight
Summary

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