ILP: CONTROL FLOW

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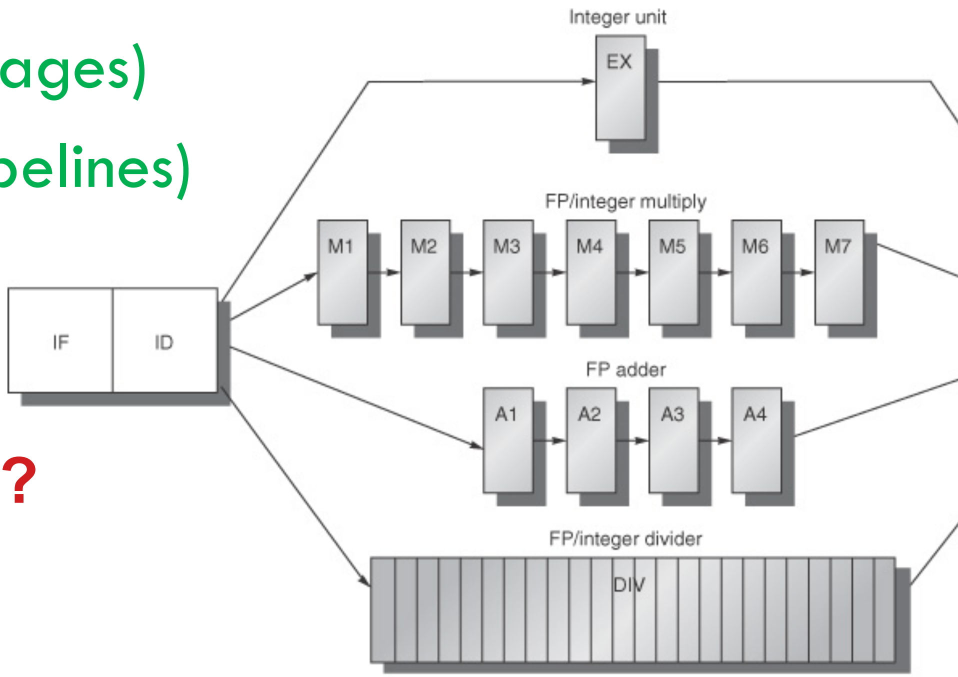
Overview

- Announcement
  - Homework 2 submission deadline: Feb. 13th
- This lecture
  - Performance bottleneck
  - Program flow
  - Branch instructions
  - Branch prediction

Performance Bottleneck

- Key performance limitation
  - Number of instructions fetched per second is limited
- How to increase fetch performance?
  - Deeper fetch (multiple stages)
  - Wider fetch (multiple pipelines)

How to handle branches?



Impact of Branches

- Example C code
  - No structural/data hazards
  - What is fetch rate (IPS)?

```
do {
        sum = sum + i;
        i = i – 1;
} while(i > 0);
```

- Five-stage pipeline
  - Cycle time = 10ns

Assembly code:

```
Loop:  ADD   R1, R1, R2
       ADDI  R2, R2, #-1
       BNEQ  R2, R0, Loop
       stall
```

Fetch | Decode | Execute | Memory | Writeback

Impact of Branches

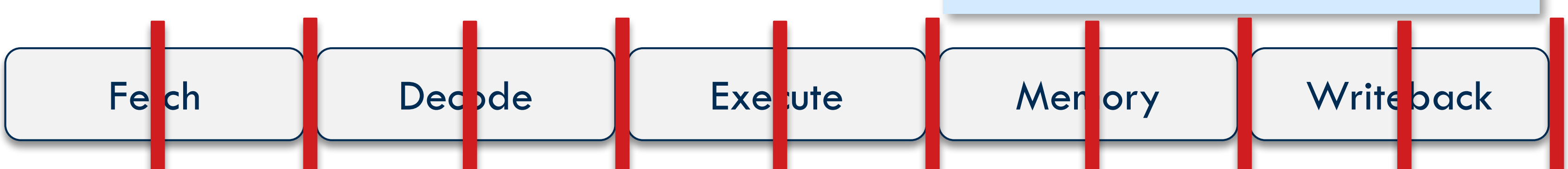
- Example C code
  - No structural/data hazards
  - What is fetch rate (IPS)?

```
do {
    sum = sum + i;
    i = i – 1;
} while(i > 0);
```

- Ten-stage pipeline
  - Cycle time = 5ns

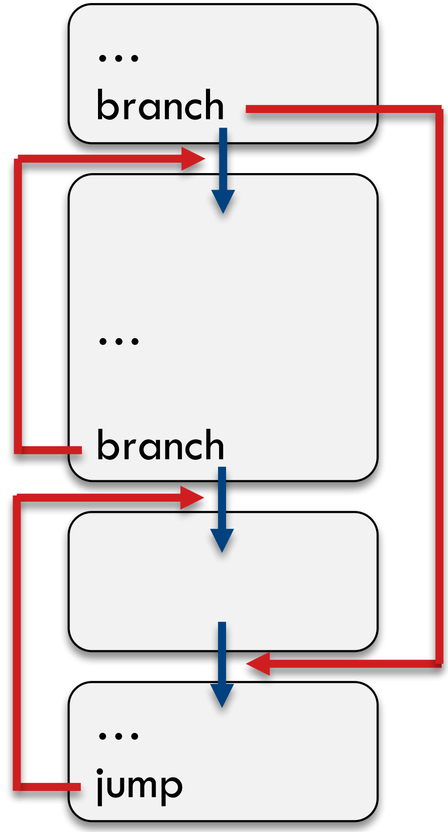
Assembly code:

```
Loop:  ADD   R1, R1, R2
       ADDI  R2, R2, #-1
       BNEQ  R2, R0, Loop
       stall
       stall
       stall
```



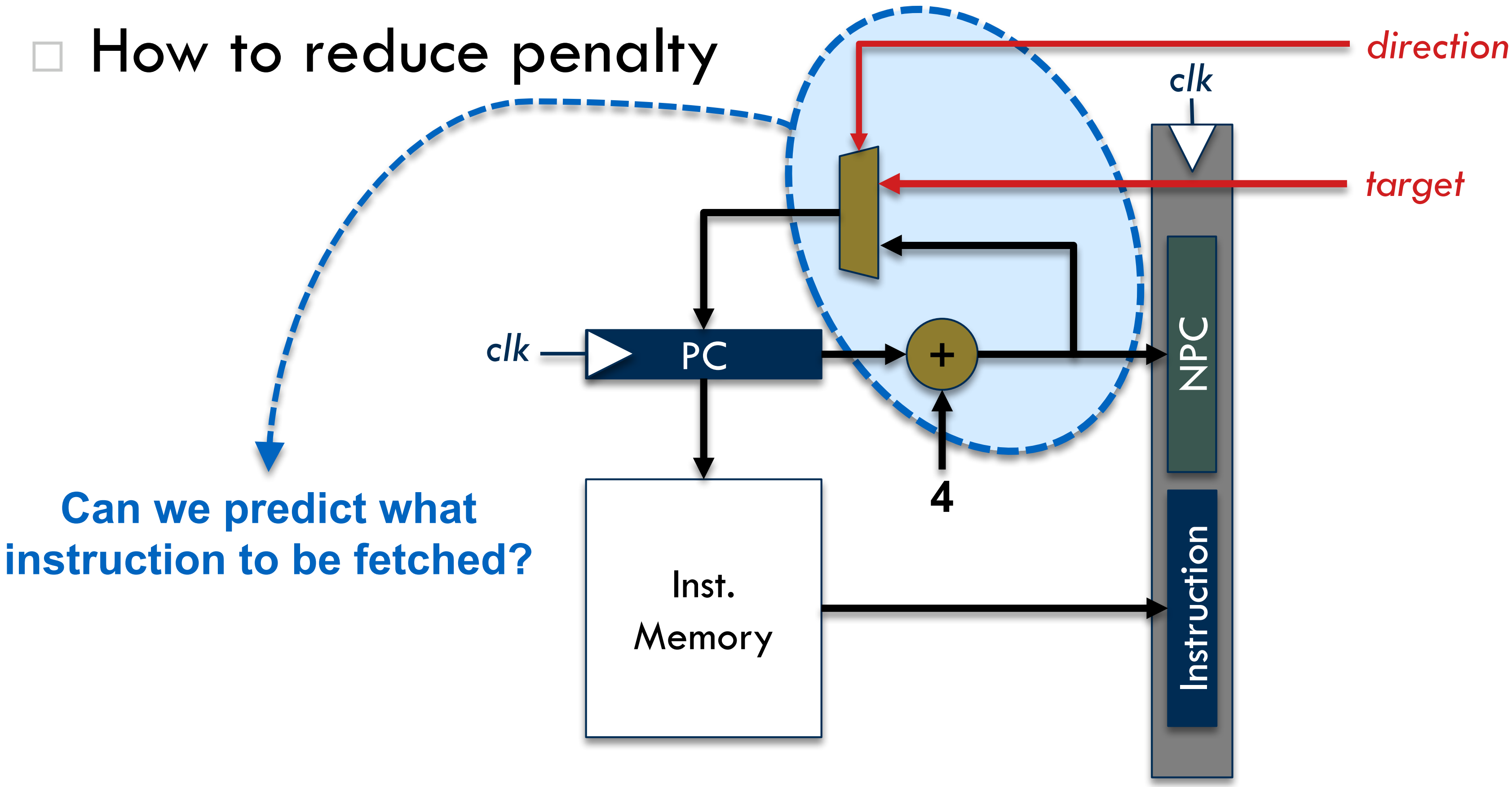
Program Flow

- A program contains basic blocks
  - Only one entry and one exit point per basic block
- Branches
  - Conditional vs. unconditional
    - How to check conditions
    - Jumps, calls, and returns
  - Target address
    - Absolute address
    - Relative to the program counter



Branch Instructions

- Branch penalty due to unknown outcome
  - Direction and target
- How to reduce penalty



Branch Prediction

- How to predict the outcome of a branch
  - Profiling the entire program
  - Predict based on common cases

Example C/C++ code:

```
      i = 10000;
      do {
            r = i%4;
=>          if(r != 0) {
                  sum = sum + i;
            }
            i = i – 1;
=>    } while(i > 0);
```

How many branches?

Branch Prediction

- How to predict the outcome of a branch
  - Profiling the entire program
  - Predict based on common cases

Assembly code:

```
      ADDI  R1, R0, #10000
do:
      ANDI  R2, R1, #3
      BEQ   R2, R0, skp
      ADD   R3, R3, R1
skp:  ADDI  R1, R1, #-1
      BNEQ  R1, R0, do
```

	TAKEN	NOT-TAKEN
branch-1	2500	7500
branch-2	9999	1

Branch Prediction

- The goal of branch prediction
  - To avoid stall cycles in fetch stage
- Types
  - Static prediction (based on direction or profile)
    - Always not-taken
      - Target = next PC
    - Always taken
      - Target = unknown
  - Dynamic prediction
    - Special hardware using PC

Which ones are influenced

a. Performance
b. Energy
c. Power

Branch Prediction/Misprediction

- Prediction accuracy?
  - A: always not-taken

    0.01

  - B: always taken

    0.99

```
i = 100;
do {
    sum = sum + i;
    i = i – 1;
} while(i > 0);
```

Problem

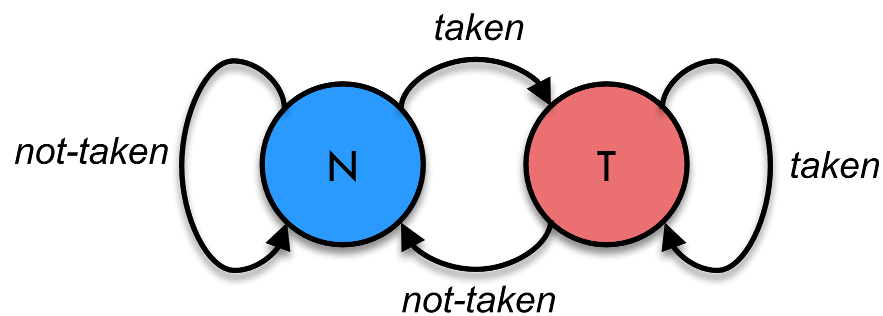
- Compute IPC of a scalar processor when there are
  - no data/structural hazards, only control hazards,
  - every 5th instruction is a branch, and
  - 90% branch prediction accuracy
- IPC = 1/ (1 + stalls per instruction)
- = 1/(1 + 0.2x0.1x1) = 0.98

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

Simple Dynamic Predictors

- One-bit branch predictor
  - Keep track of and use the outcome of last executed branch



- Prediction accuracy

  - A single predictor shared by multiple branches
  - Two mispredictions for loops (1 entry and 1 exit)

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

branch-1

branch-2