

# Predication

## Introduction

1. Some branches are difficult to predict even with sophisticated branch predictors
  - Compiler can help avoid some of these branches

## Predication

1. Branch prediction: Guessing where program is going
  - No penalty if correct (0 instructions)
  - Huge penalty if incorrect (12-stage pipeline with 4 instructions/cycle -> 48)
2. Predication: Do work of both directions (taken/not taken)
  - Waste up to 50%
  - Throw away work from wrong path
3. Loop: Typically use branch prediction (more loops -> more predictable)
  - Using predication will waste many cycles and makes little sense
4. Function call/return: Predict since the branch is always taken
5. Large if-then-else: Predict
  - If length of branch is 100 cycles either way, we will waste these 100 cycles compared to the ~50 we wasted due to a branch miss in the above example
6. Small if-then-else: Predication unless we're certain the branch predictor will be highly accurate
  - If length of branch is 5 cycles either way, we always waste 5 cycles with predication
  - Branch prediction results in 50 wasted cycles in the case of a missed prediction
  - 100% of time we waste 5 cycles with predication -> 5
  - 10% of time we waste 50 cycles with branch prediction -> 5
    - This is the break-even point
    - If size of branch is smaller or branch prediction performs worse, this biases the result in favor of predication

## If Conversion

1. if(cond) { x = arr[i]; y++; } else { x = arr[j]; y--; }
  - x1 = arr[i];
  - x2 = arr[j];
  - y1 = y + 1;
  - y2 = y - 1;
  - x = cond ? x1 : x2; -> Now we have two branches
  - y = cond ? y1 : y2; -> Now we have two branches
2. Need some sort of conditional move instruction in hardware
  - MOV x, x1, cond

## Conditional Move

1. MIPS
  - MOVZ Rd, Rs, Rt -> if(Rt == 0) Rd = Rs;
  - MOVN Rd, Rs, Rt -> if(Rt != 0) Rd = Rs;
2. x86
  - CMOVZ, CMOVNZ, CMOVGT, ... -> if(cc) Dst = Src;
  - Based on all of the condition codes

## MovZ MovN Quiz

1. Consider the following program:
  - BEQZ R1, Else

- ADDI R2, R2, 1
  - B End
  - Else: ADDI R3, R3, 1
  - End:
2. How do we rewrite this with conditional moves?
    - ADDI R4, R2, 1
    - ADDI R5, R3, 1
    - MOVN R2, R4, R1
    - MOVZ R3, R5, R1

## MovZ MovN Performance

1. 80% branch accuracy, 40-instruction penalty on missed branch
  - When the branch is not taken we execute 3 instructions
  - When the branch is taken we execute 2 instructions
  - Assuming the branch is balanced, we execute an average of 2.5 instructions
  - $2.5 + 0.2 * 40 = 10.5$  instructions
2. If-conversion costs 4 instructions

## MovZ MovN Performance Quiz

1. Assumptions:
  - Branch is taken 50% of the time
  - 30-instruction misprediction penalty
2. If-conversion is better when prediction accuracy is below...
  - $2.5 + \text{Accuracy} * 30 = 4$
  - $\text{Accuracy} = (4 - 2.5) / 30 = 0.05$  (5%)
  - If prediction accuracy is below 95%, predication is better

## MOVc Summary

1. Require compiler support for if-conversion
  - Not fully backwards-compatible (old code won't use these instructions)
2. Removes hard-to-predict branches
3. More registers needed
  - Keep results from both parts
4. More instructions executed
  - Executing both paths
  - MOVc to select actual results
5. Full predication: Can change ISA such that all instructions are conditional
  - Requires extensive support in instruction set
  - Every instruction computes a result but may or may not store it

## Full Predication Hardware Support

1. MOVcc
  - Separate opcode
2. Full Predication
  - Add condition bits to every instruction
  - Intel Itanium: (qp) ADD R1, R2, R3
    - qp: Qualifying predicate
    - Instruction has 41 bits, low 6 bits are 1-bit condition registers

## Full Predication Example

1. Applying full predication to the example program above
  - MP.EQZ P1, P2, R1 (sets qualifying predicate bits)
  - (p2) ADDI R2, R2, 1
  - (p1) ADDI R3, R3, 1
2. Don't require additional registers
3. No overhead with moving between registers since we're storing directly in the result

## Full Predication Quiz

1. Consider the following program:
  - BEQZ R2, ELSE
  - ADD R1, R1, 1
  - B DONE
  - ELSE: ADD R1, R1, -1
  - DONE:
2. Convert to full predication version
  - MP.EQZ P1, P2, R2 (P1 -> R2 == 0, P2 -> R2 != 0)
  - (P2) ADD R1, R1, 1
  - (P1) ADD R1, R1, -1
3. Assuming
  - CPI = 0.5 without mispredictions
  - Misprediction penalty is 10 cycles
4. Do if-conversion if BEQZ prediction is < % correct
  - $0.5 * (2 + 3) / 2 + \text{Accuracy} * 10 = 3 / 2$
  - $1.25 + \text{Accuracy} * 10 = 1.5$
  - $\text{Accuracy} = 0.25 / 10 = 1 / 40 = 2.5\%$
  - Require 97.5% accuracy

## Conclusion

1. Branch prediction and predication handle control hazards
  - Need to consider how data hazards are handled while maintaining instruction flow in our pipeline