# Understanding the Differences Between Value Prediction and Instruction Reuse

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# Introduction

**Instructions perform same computation repeatedly**

- produce same results again and again → **Redundancy!**

**Exploitation → Collapse true dependences**

**Two techniques**

- **Value Prediction (VP):** predict results
  → perform dependent computation in parallel
- **Instruction Reuse (IR):** reuse earlier results
  → avoid performing same computation again

# Purpose of this work

**Effectiveness of any technique depends on**

- how well it performs by itself
- how it interacts with base $\mu$-arch

**VP and IR are different techniques**

➔ interact differently

**Purpose**

**Understand the differences and their impact**

➔ will help in designing better hybrid schemes

# Outline

❶ VP and IR ➔ differences

❷ Potential for capturing redundancy

❸ Interactions: Qualitative

❹ Interactions: Some results

In the paper

- More results
- Estimate of fraction of total redundancy captured by IR

# VP and IR

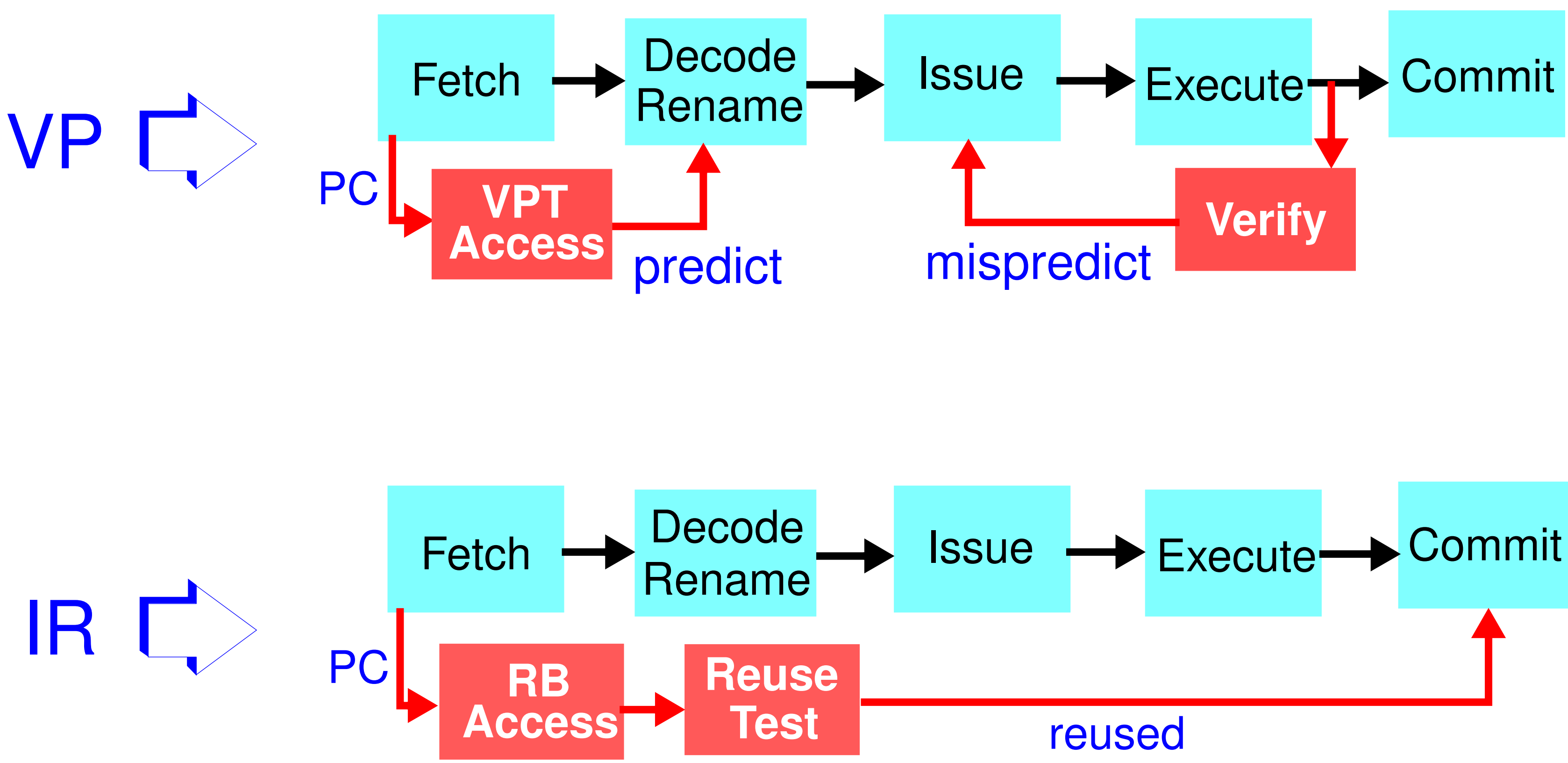
## VP: Main idea

- Save instruction results in **VP Table** (VPT)
- Next time
  - predict result → dependent inst. free to execute
  - if mispredicted → re-execute dependent inst.

## IR: Main idea

- Save instruction inputs and result in **Reuse Buffer** (RB)
- Next time
  - check RB for instruction entry
  - if inputs same → reuse result → skip computation

# Pipelines


VP
Fetch
Decode
Rename
Issue
Execute
Commit
PC
VPT
Access
predict
mispredict
Verify
IR
Fetch
Decode
Rename
Issue
Execute
Commit
PC
RB
Access
Reuse
Test
reused

# Differences

**VP:** Verifies results **after** Use → **speculative**

**IR :** Verifies results **before** Use → **non-speculative**

Due to this, they **differ** in

❶ amount of redundancy they capture

❷ their interaction with base μ-arch

→ hence differ in performance gained

# Potential for Capturing Redundancy

**IR: conservative**

- inst not reused if
  - inputs not ready, or
  - they are different

**VP: aggressive**

- can correctly predict in above cases

**VP captures more redundancy than IR**

# Outline

1. ~~VP and IR → differences~~
2. ~~Potential for capturing redundancy~~
3. Interactions: Qualitative
4. Interactions: Some Results

# $\mu$-arch Interactions

**VP and IR have different impacts on**

- Branch prediction
- Contention for resources (FU, cache ports, etc.)
- Execution latency of inst.

# Interaction: Branches

**Branch misprediction ➔ inhibits performance**

- penalty less if misprediction detected sooner

**VP and IR impact branch misprediction penalty**

❶ Both collapse true dependences

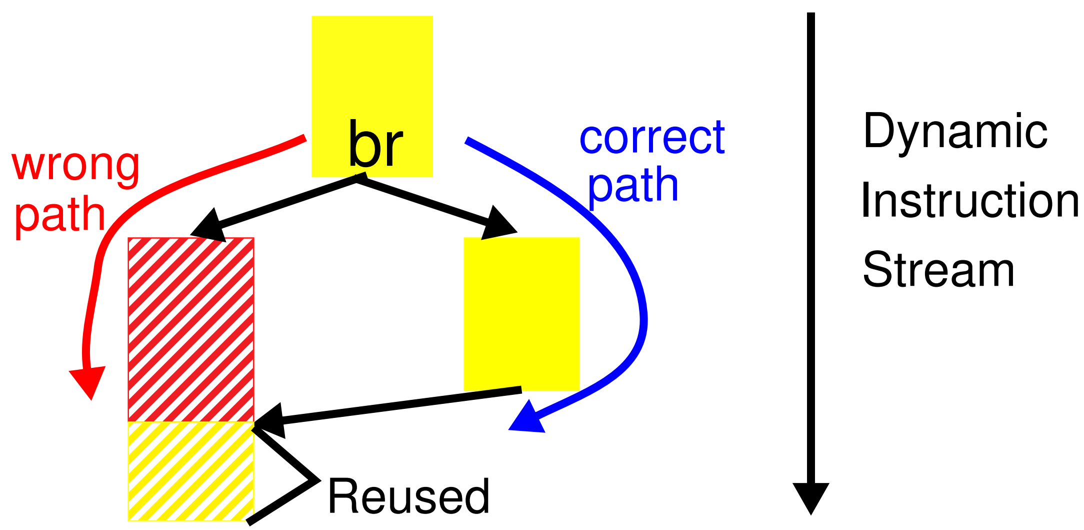
- thereby can execute branches sooner
  - ➔ detect misprediction early
  - ➔ reduce misprediction penalty

# Interaction: IR Specific

## ❷ IR reduces branch misprediction penalty further

① by detecting misprediction still earlier

② by recovering useful work from squashes



# Interaction: VP Specific

## ❸ VP tends to increase branch misprediction penalty

- Branches execute with **value-speculative operands**

They can be resolved

immediately
(operands value speculative)

**spurious misprediction**

after their **true**
operand values are known

**delayed branch resolution**

**Either way more cycles lost due to branch misprediction**

# Resource Contention

**Inst. contends for different <u>resources</u> in pipeline**

(e.g., FU, cache ports, inst. issue ports)

**Interactions**

❶ VP and IR may ↑ or ↓ contention

- they cluster or spread requests for resources

❷ IR tends to reduce contention

- reused instructions don’t execute

❸ VP tends to increase contention

- mispredicted instructions re-execute

# Execution Latency of Instructions

- **VP**: instructions execute to verify prediction
  - exec. latency of individual inst. not affected
- **IR**: reused instructions don’t execute
  - exec. latency eliminated

# Impacts: Quantitative

**VP :** 16K-entry VPT Table, 4-way set assoc. 2-bit conf. counters

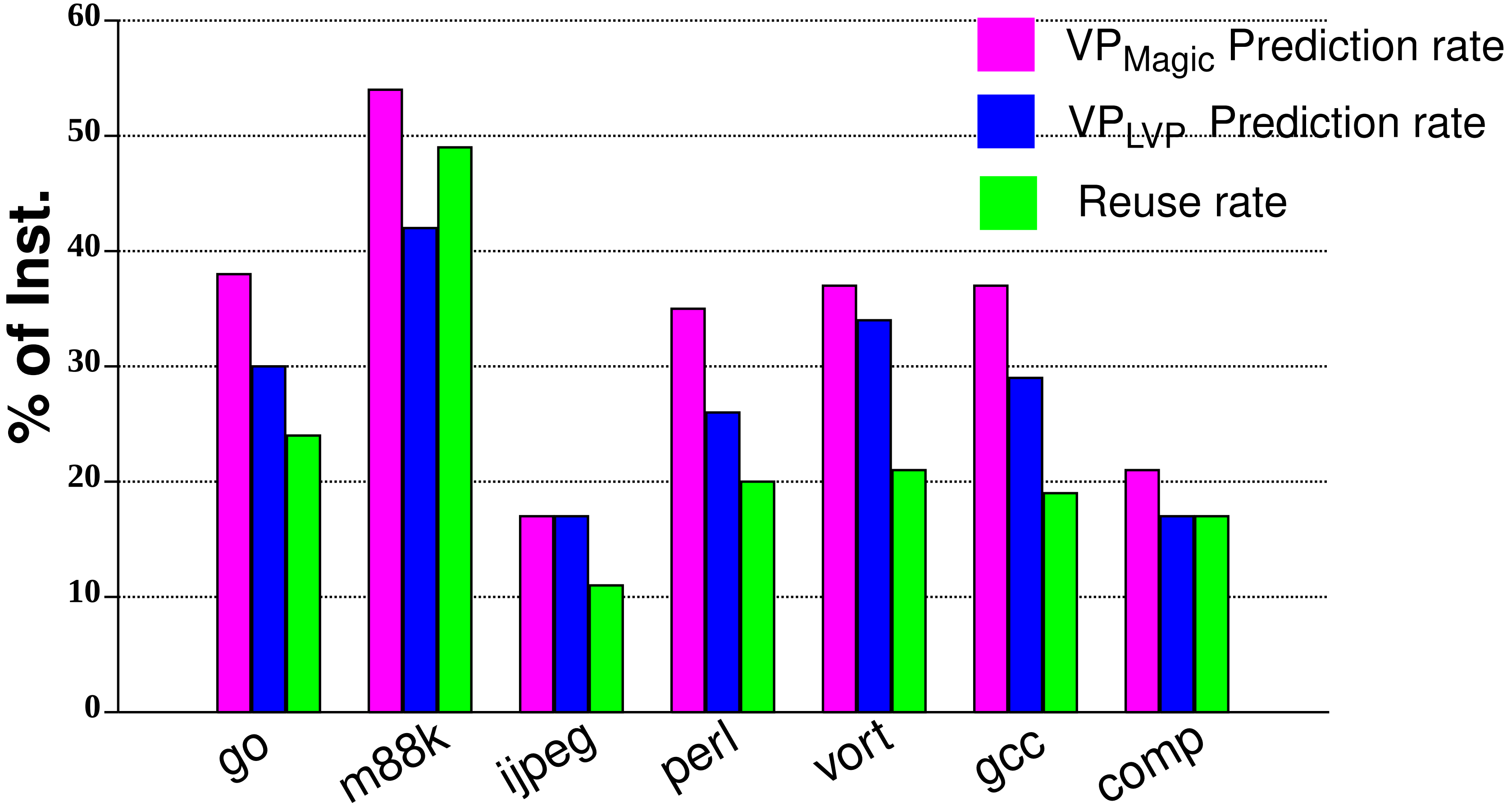
- $VP_{Magic}$: 4 instances per instruction
  - Correct prediction chosen magically
- $VP_{LVP}$ : Last value used as prediction
- Selective re-issuing on misprediction

**IR :** 4K-entry Reuse Buffer, 4-way set assoc.

- 4 instances per instruction
  - Reuse test performed in parallel; successful one is reused

**Machine :** 4-way OOO execution, 32 inst. window, 16K-entry Gshare

# Value Prediction and Reuse Rates



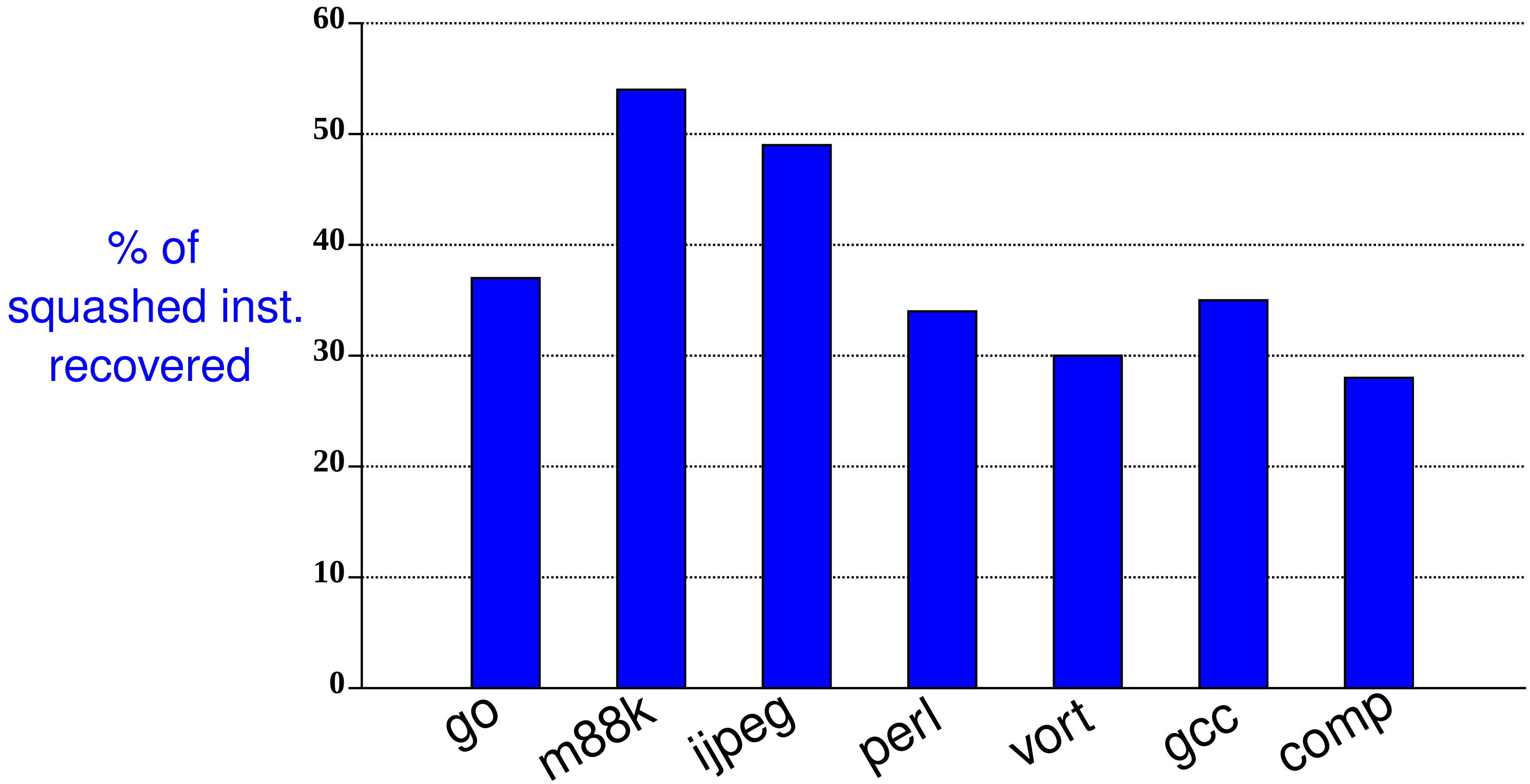

**More instructions correctly predicted than reused**

# Value Misprediction Rates

| Benchmarks | $VP_{Magic}$ (%) | $VP_{LVP}$ (%) |
|---|---|---|
| go | 3.3 | 4.5 |
| m88ksim | 0.6 | 2.7 |
| ijpeg | 0.9 | 4.4 |
| perl | 1.2 | 1.7 |
| vortex | 1.1 | 3.3 |
| gcc | 1.9 | 3.9 |
| compress | 0.2 | 0.6 |

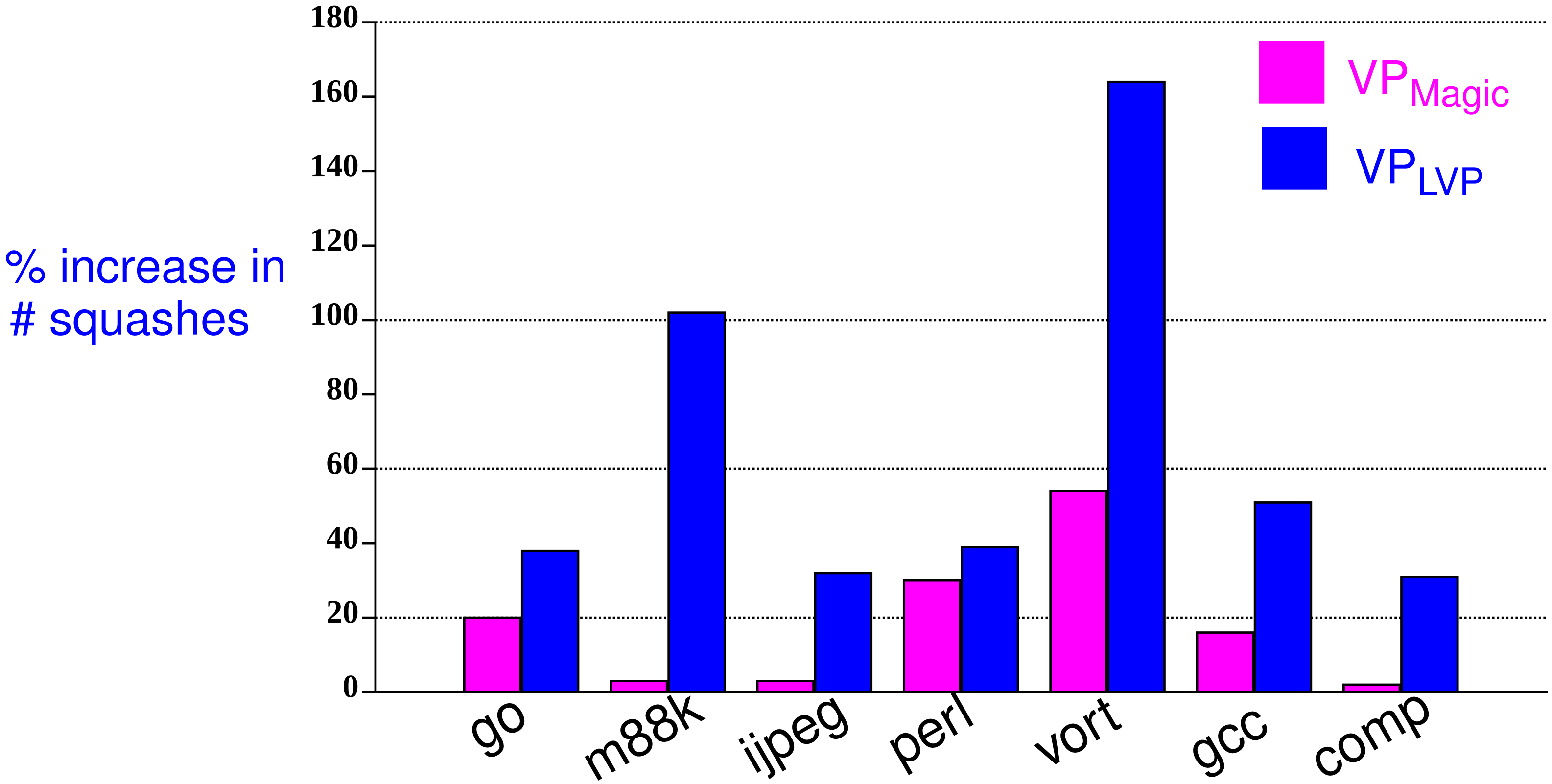
**Misprediction rates: ❶ overall low ❷ but higher for $VP_{LVP}$**

# Squashed Inst. Recovered by IR




**Faster recovery from branch misprediction → less penalty**

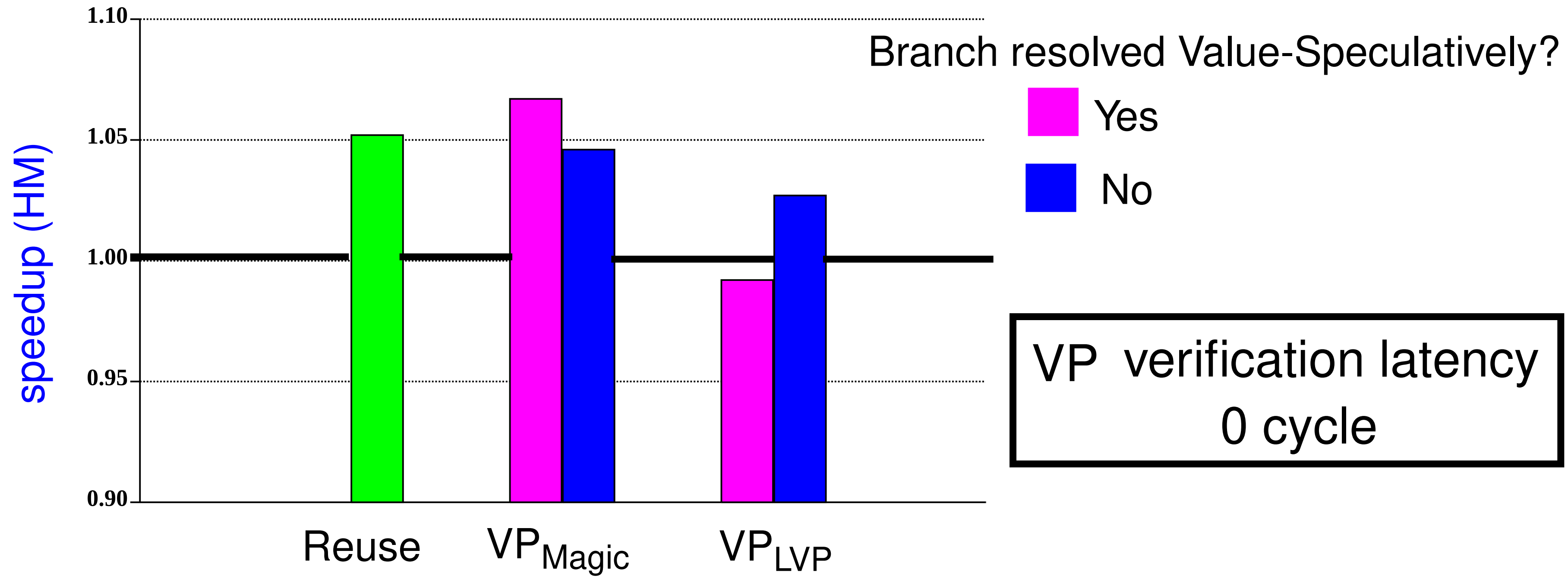
# Spurious Branch Mispredictions




Significant spurious mispredictions caused

- especially for $VP_{LVP}$ where value mispredictions are more

# Performance




VP verification latency
0 cycle

**VP performance sensitive to when branches resolve**

VP mispredict rate → LOW → resolving immediately → good

VP mispredict rate → HIGH → resolving immediately → slowdown

# Summary

❶ **Both VP and IR collapse true dependences**

- **VP**: speculative (verifies results after use)
- **IR**: non-speculative (verifies results before use)

❷ **VP higher potential for capturing redundancy**

- but may interact adversely with branch prediction

❸ **IR is conservative**

- but alleviates branch misprediction penalty
- and is always correct

❹ **Also in paper : an estimation of how conservative is IR**