A Study of Control Independence

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Introduction

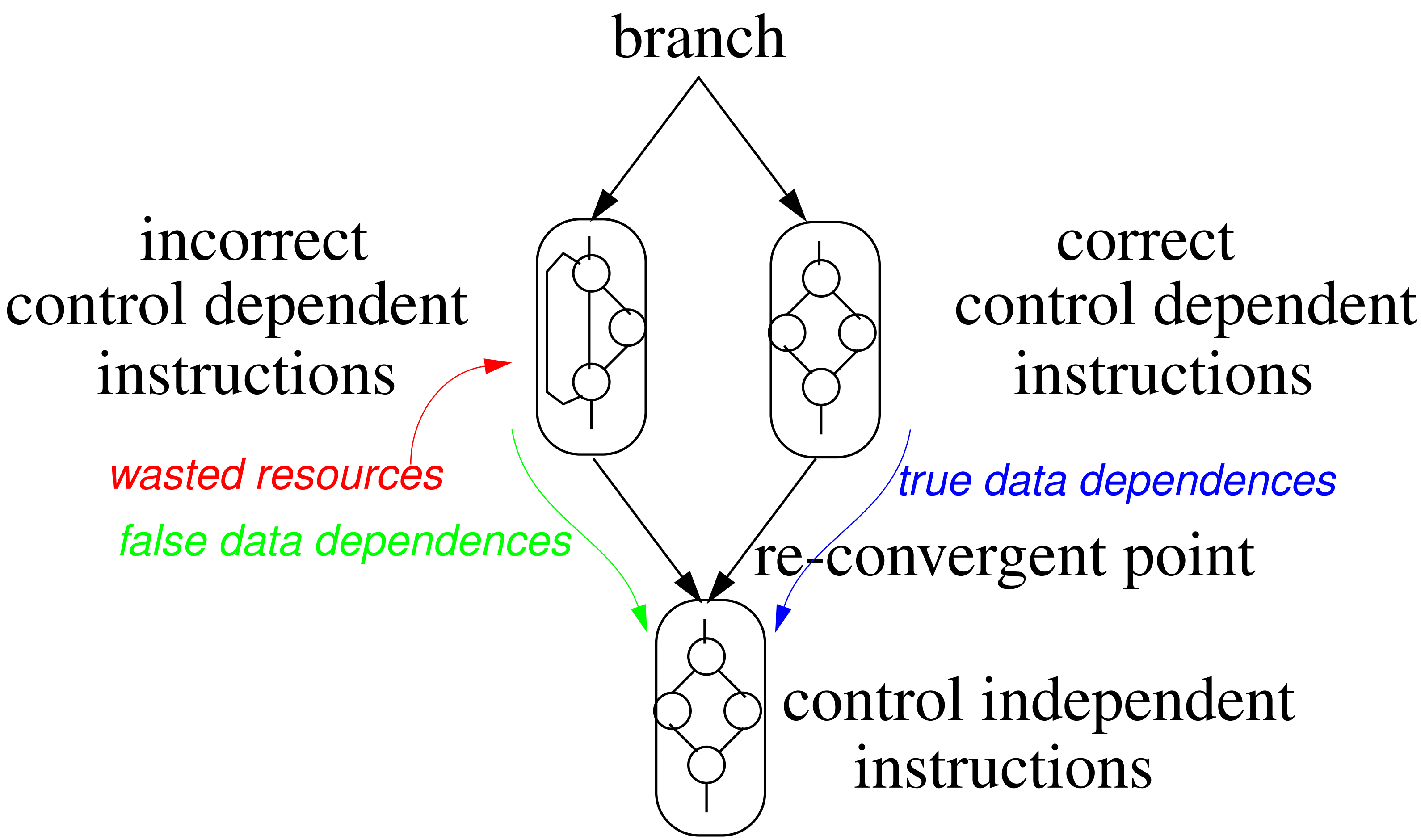
- High instruction-level parallelism (ILP)
  - requires large instruction scheduling window
  - branches make this difficult
- Branches introduce control dependences
  - must execute branch to fetch next instructions
  - correct branch prediction/speculation: essentially eliminates control dependences
  - mispredictions are still a major bottleneck: complete squashing

Introduction

- Solutions to branch misprediction bottleneck

1. better branch prediction
2. forms of multi-path execution
3. predication
4. control independence

Control Independence



Goals

1. Establish new performance bounds of control independence under implementation constraints
   - window size
   - fetch/issue width
2. Identify and quantify primary limiting factors
3. Assess basic implementation requirements and complexity

- Goals 1 and 2 are the focus of this talk
  - Inspired by Lam & Wilson limit study
  - Want to refine understanding of control independence
  - Can aid control independence design

Notation

- WR
  - Model Wasted Resources due to incorrect control dependent instructions
  - Resources => window space and pipeline bandwidth
  - Conversely: nWR => no wasted resources
- FD
  - Model False Dependences created by incorrect control dependent instructions
  - Conversely: nFD => no false dependences

Models

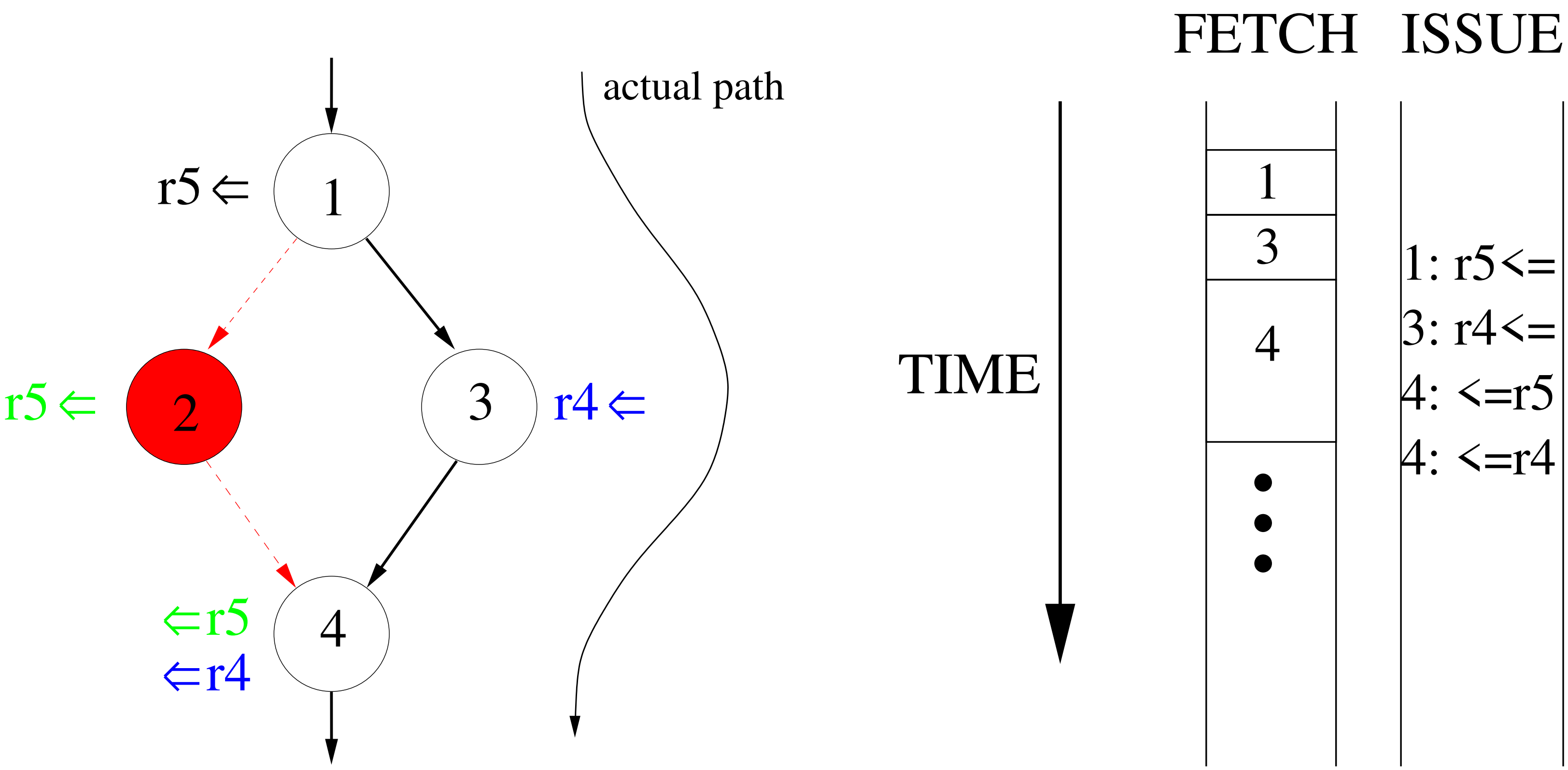
Endpoints

1. oracle: oracle branch prediction
2. base: conventional prediction/speculation

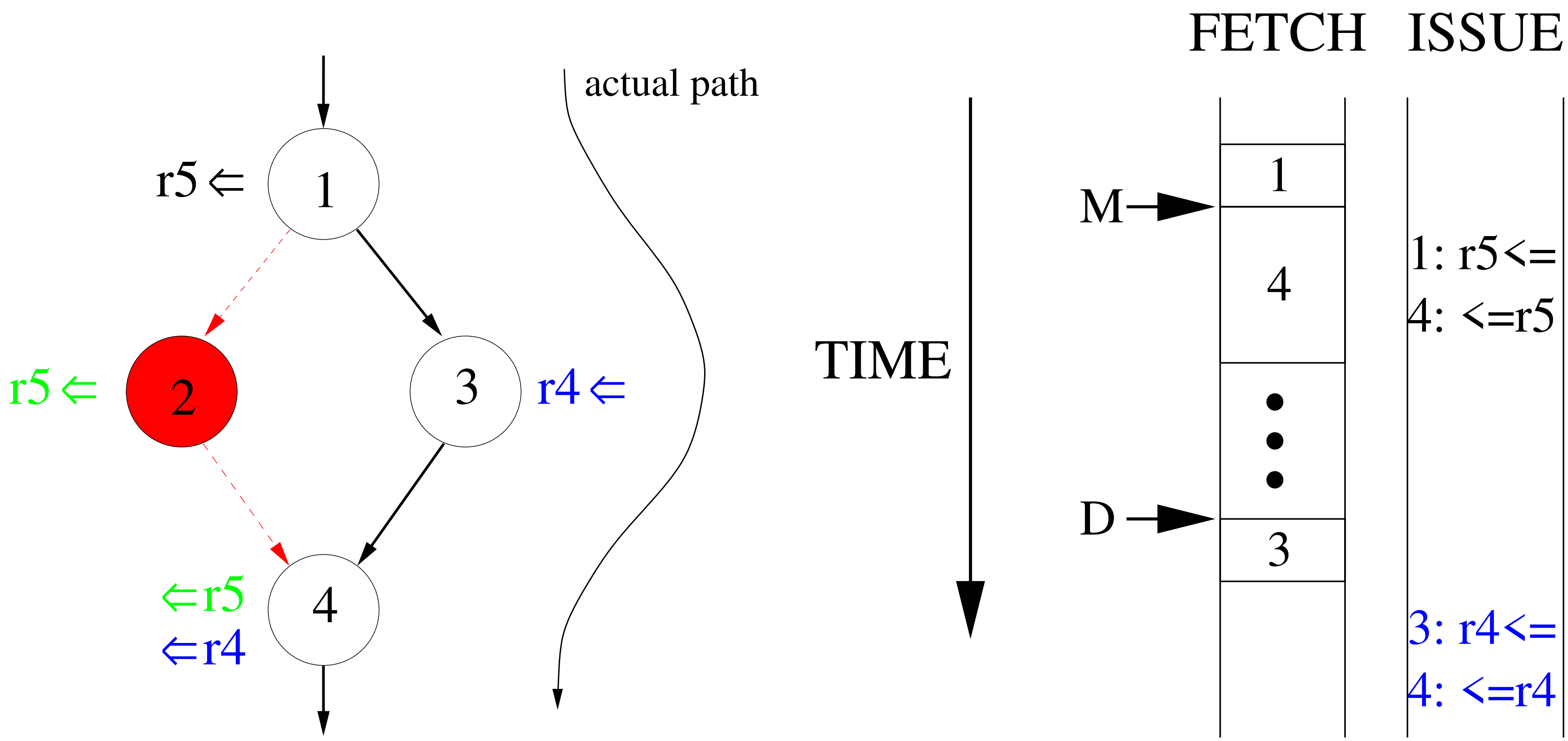
Control independence models

3. nWR-nFD: no wasted resources, no false dependences
4. nWR-FD : no wasted resources, false dependences
5. WR-nFD : wasted resources, no false dependences
6. WR-FD : wasted resources, false dependences

oracle


r5 ⇐
1
r5 ⇐
2
3
r4 ⇐
⇐r5
⇐r4
4
actual path
TIME
FETCH
ISSUE
1
3
4
1: r5<=
3: r4<=
4: <=r5
4: <=r4

nWR-nFD



actual path
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r5 ⇐
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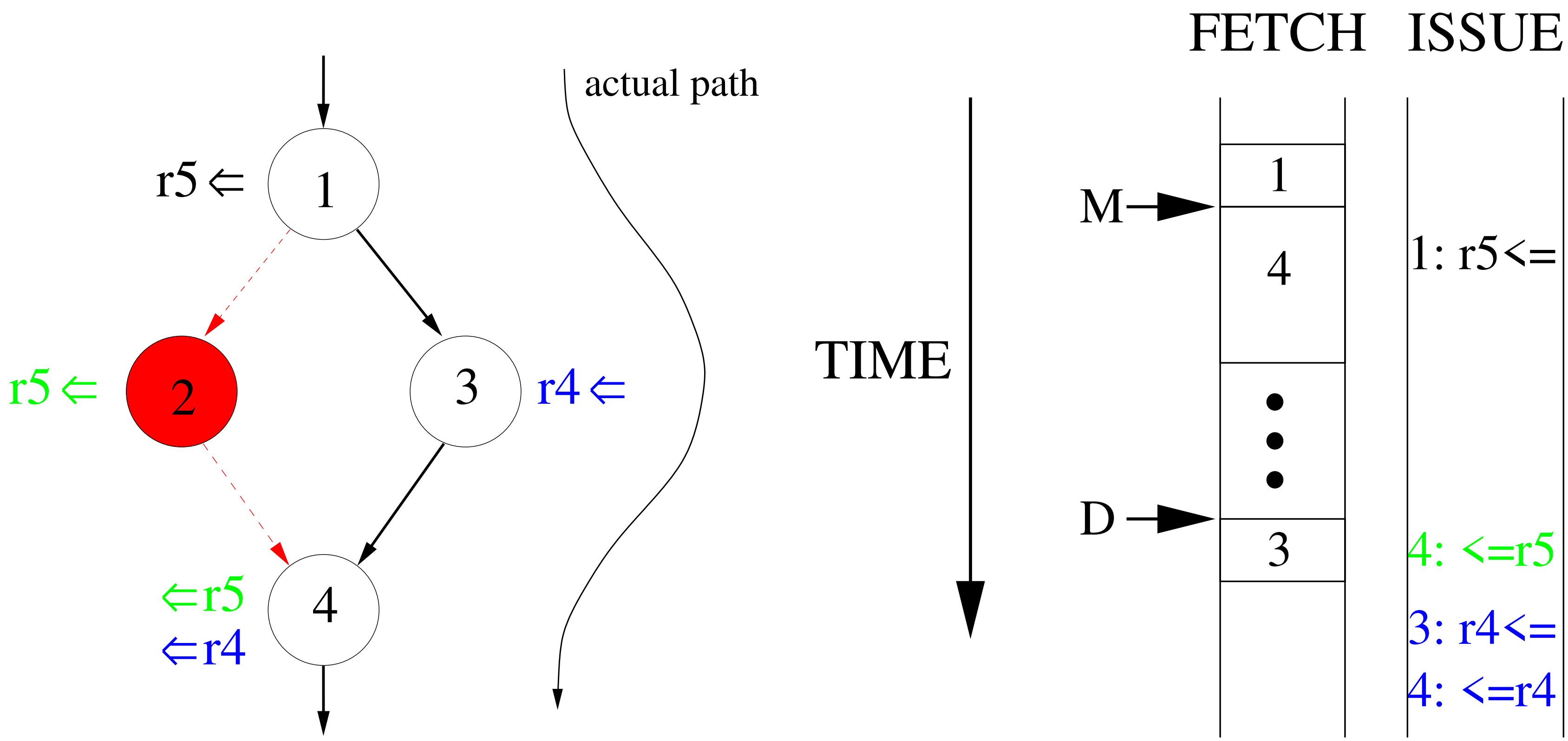
r4 ⇐
⇐r5
⇐r4
4
TIME
FETCH
ISSUE
M
D
1
4
3
1: r5<=
4: <=r5
3: r4<=
4: <=r4

nWR-FD



actual path
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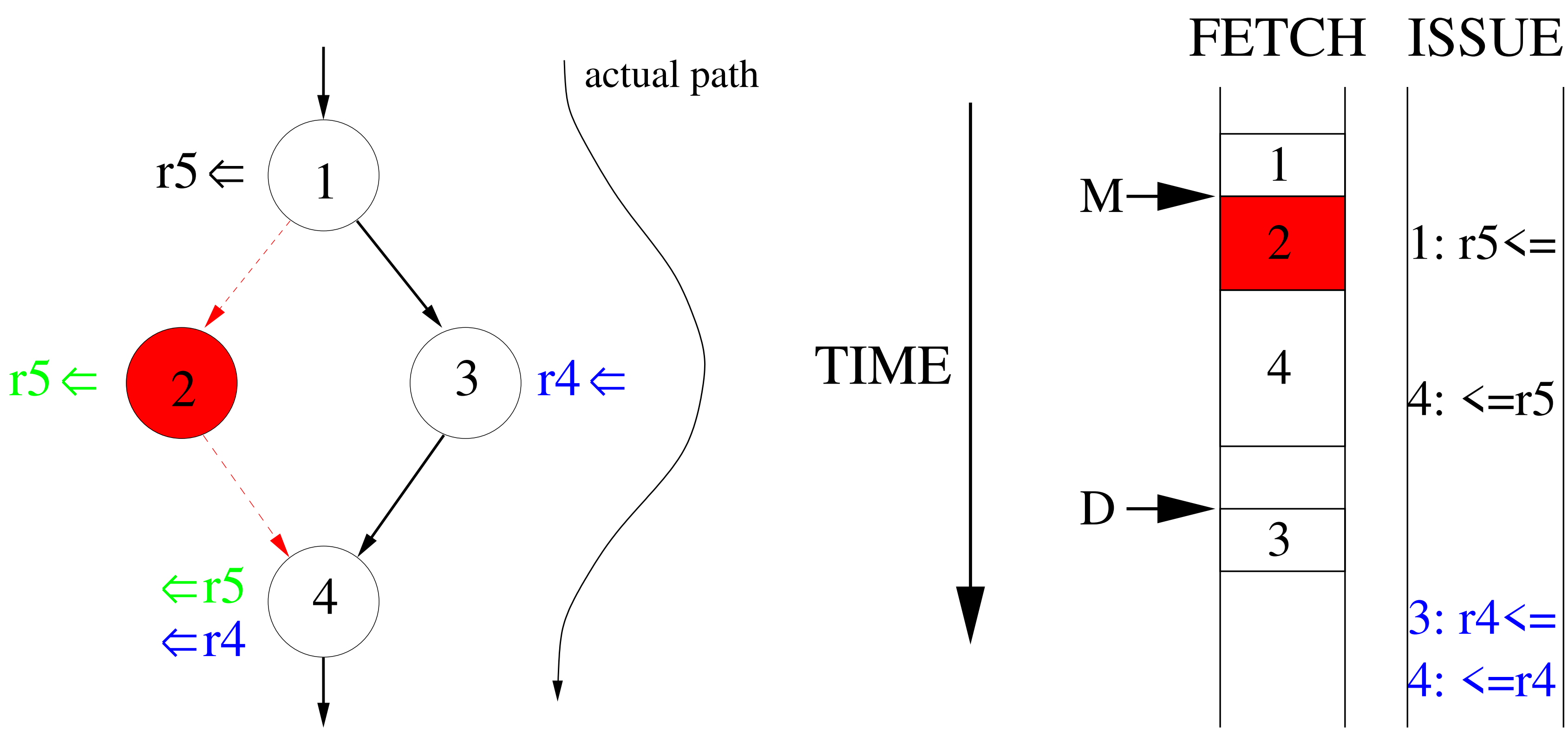
WR-nFD



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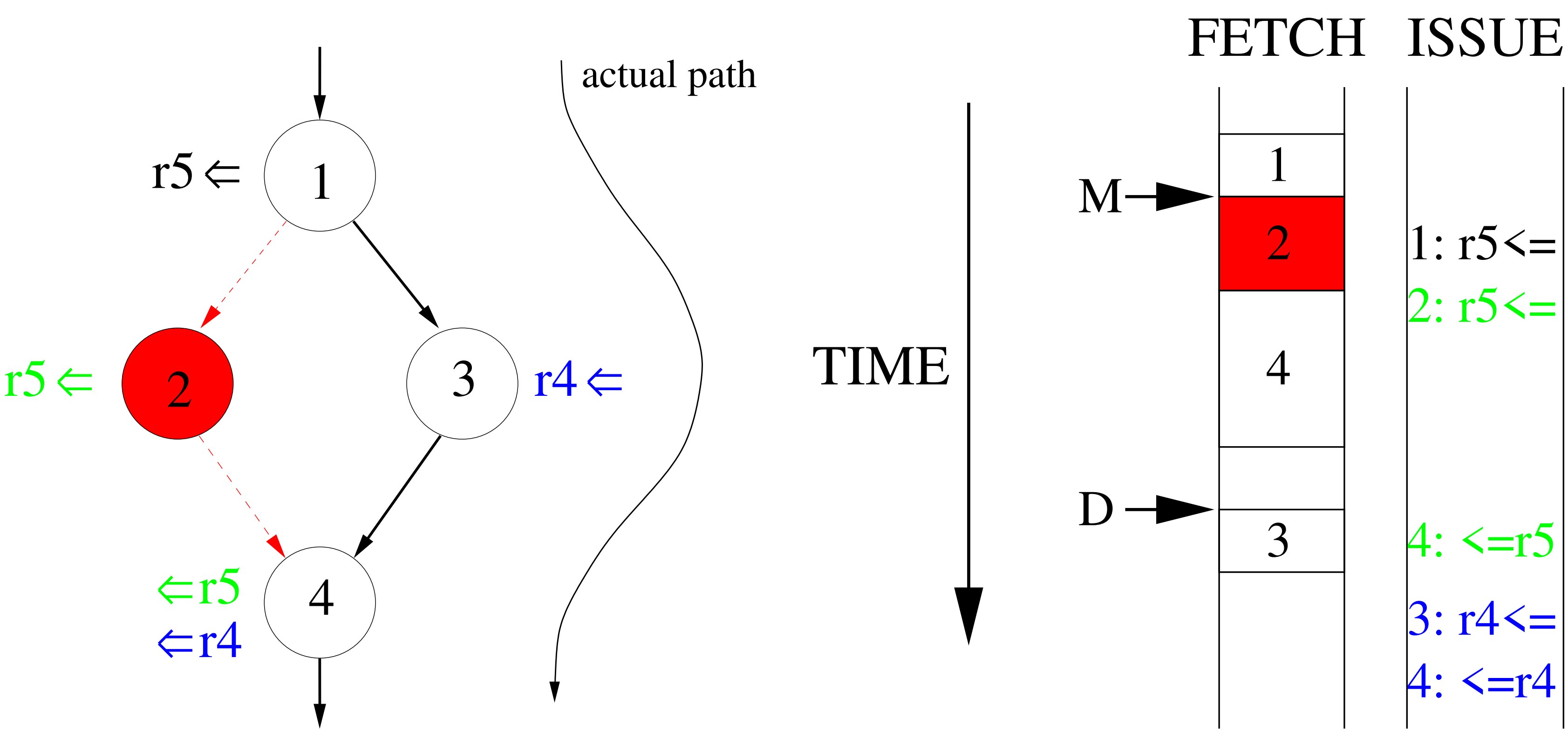
WR-FD



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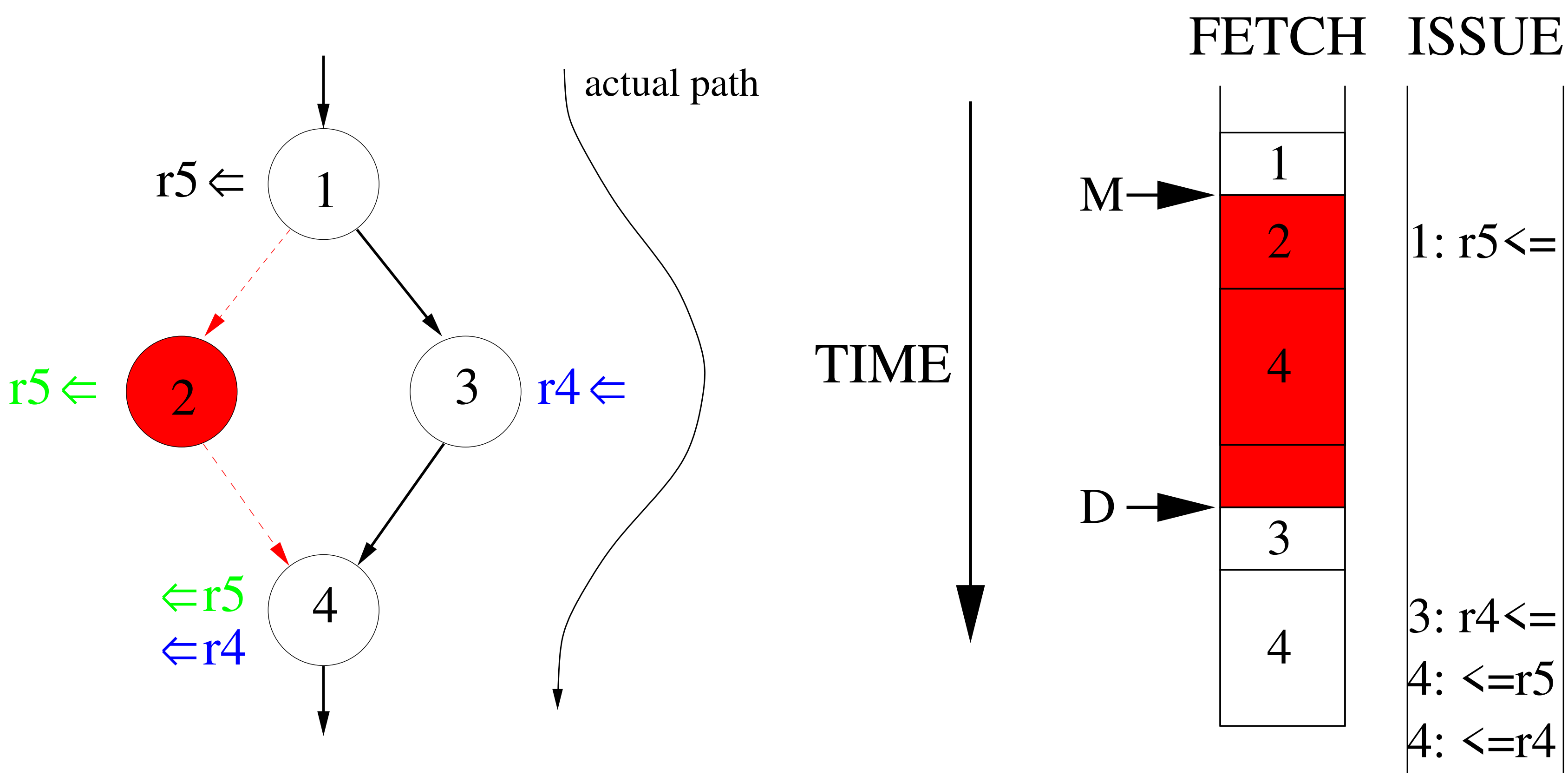
base



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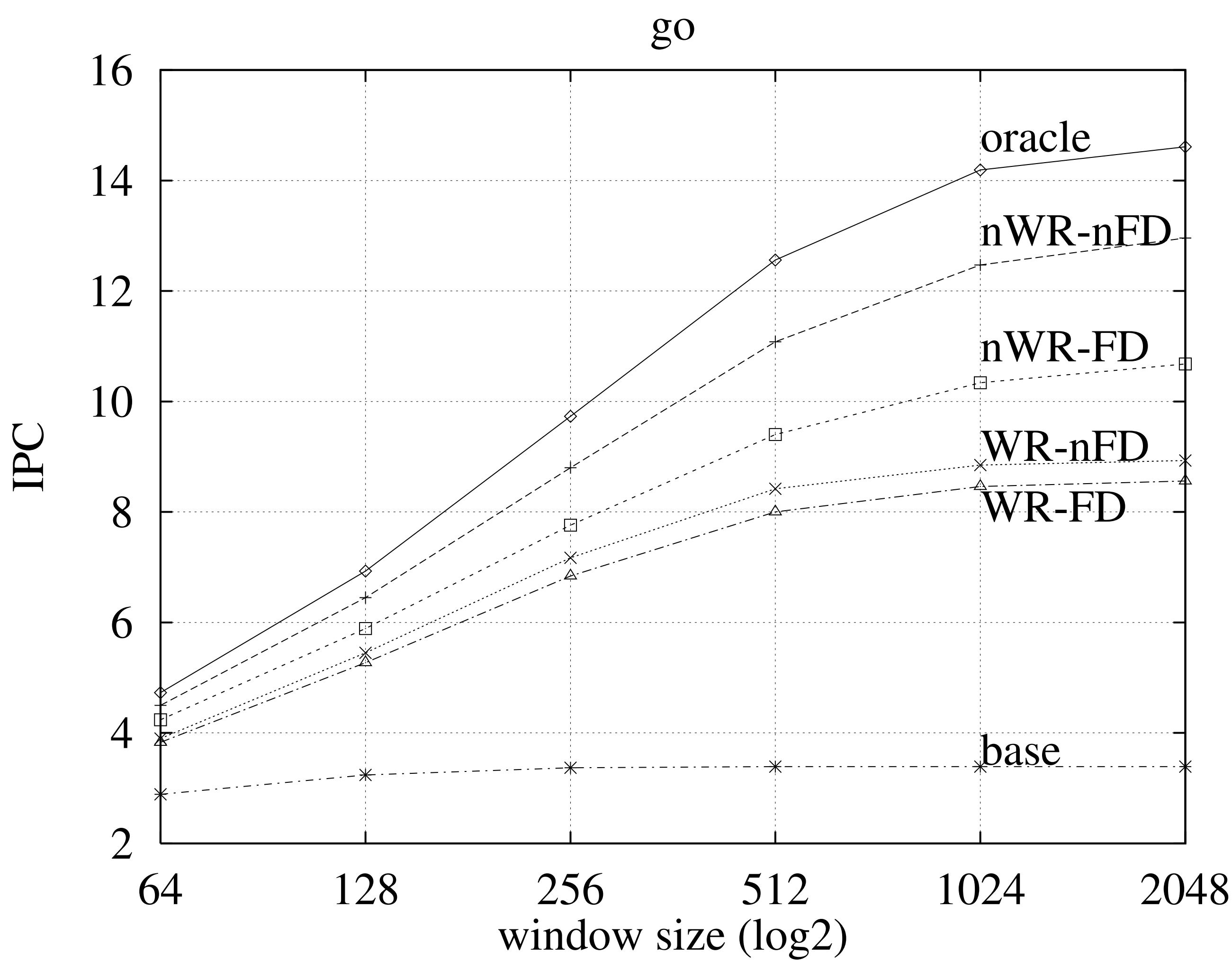
Ideal Study



go
IPC
window size (log2)
16
14
12
10
8
6
4
2
64
128
256
512
1024
2048
oracle
nWR-nFD
nWR-FD
WR-nFD
WR-FD
base

Summary of Study

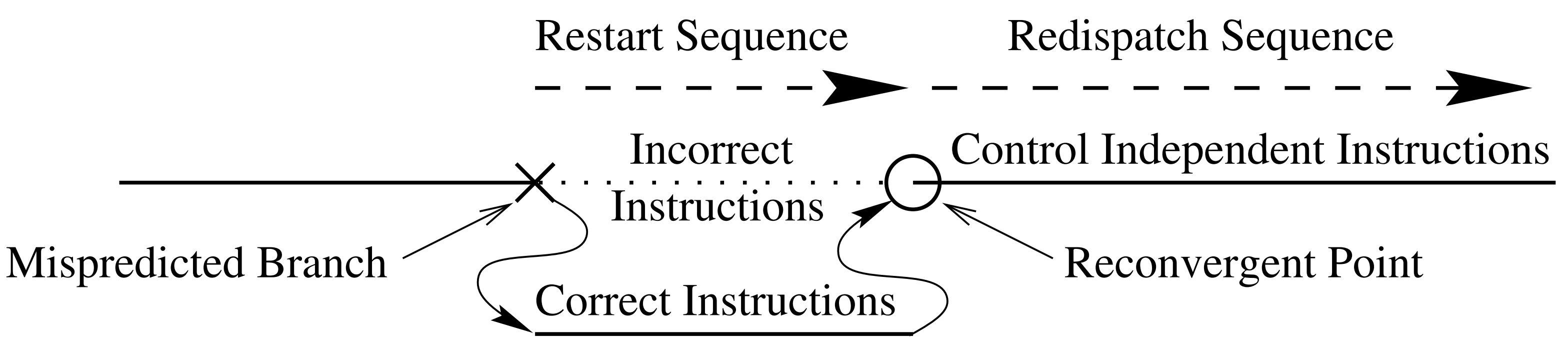
- Control independence seriously limited by incorrect control dependent instructions
  - wasted window space, fetch/execute resources
  - false data dependences
- Still has large potential
  - potentially reduce gap between oracle and real branch prediction by 1/2

Applications

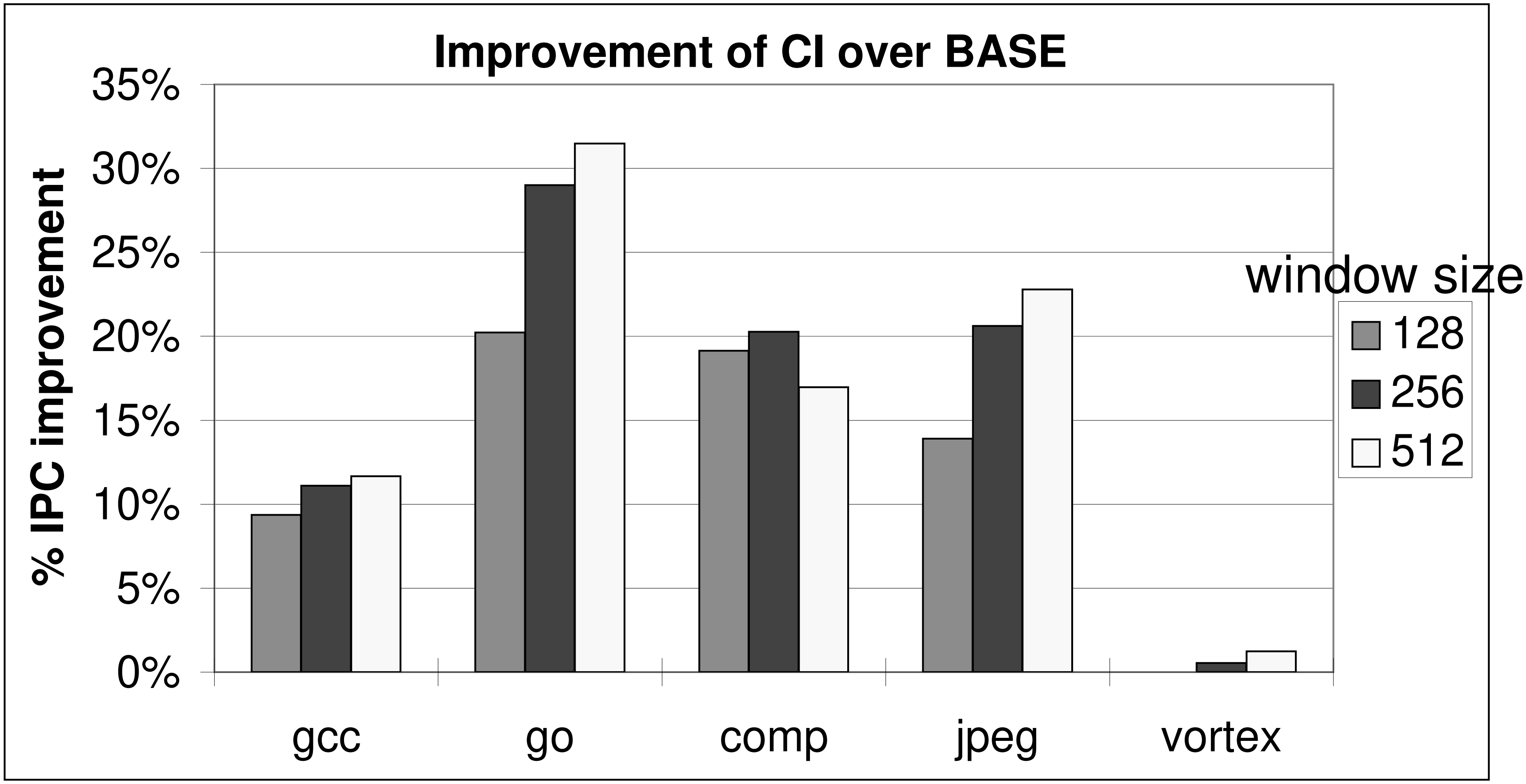
- Apply insight to guide implementations of WR-FD model
  - e.g. Trace Processors
- Large WR component suggests designs capable of “absorbing” incorrect paths
  - e.g. “expandable window” and multiple fetch units of Multiscalar Processors
  - nWR-FD model => performance potential for Multiscalar with aggressive data dependence resolution/recovery
- The study suggests several new directions...
  - nWR-nFD model
  - Interesting ways of handling data dependent/control independent instructions

Implementation Study

- Basic requirements for misprediction recovery
  - Detect the re-convergent point
  - Insert/remove instructions from middle of window
  - Form correct data dependences
  - Selectively reissue instructions



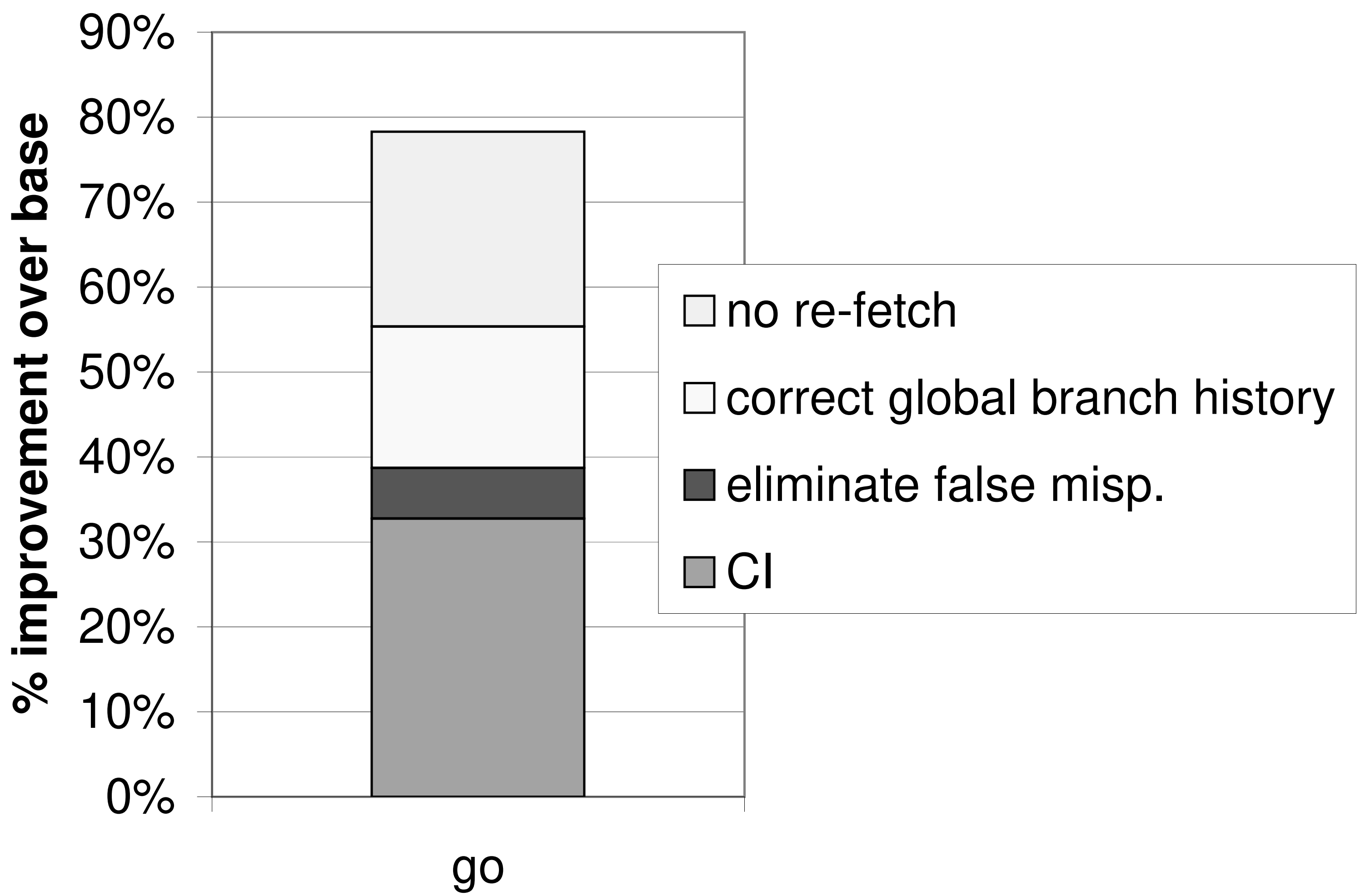
Implementation Study



Other Limiting Factors

- Factors exposed by implementation study
  - False mispredictions
  - Incoherent global branch history
  - Re-fetching/Re-dispatching control independent instructions
  - ...and many others. (See Technical Report and revisions.)

Implementation Study Revisited



Closing Remarks

- Control independence has been gaining momentum

Several limit studies	Multiscalar/Spec MT
Instruction reuse	Trace processors
CMU studies	Michigan studies
DMT	Instruction recycling in SMT

- We'll see even more control independent designs in the future => misprediction bottleneck
- Now's the time to understand the primary and secondary factors affecting control independence