

Code Generation for Branch Prediction: a review

Quinn Pham



You

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ChatGPT

As of my last knowledge update in January 2022, there might be new research papers and developments in the field of code generation for branch prediction. However, I can provide you with a list of seminal academic papers up to that point that you might consider including in a literature review on this topic:

1. **"Two-Level Adaptive Training Branch Prediction"**



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Published in 1994



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"Free Access" ACM article

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Static Branch Prediction

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 - Prediction made based on profiling information

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 - Prediction made based on static analysis

Predicting Conditional Branch Directions From Previous Runs of a Program

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Palo Alto, CA 94304

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Can we get accurate
static branch prediction by
feeding information about
previous runs of a
program to the compiler?

Fisher & Freudenberger (1992)

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 - ie. branches that can be effectively predicted at compile-time

Improving the Accuracy of Static Branch Prediction Using Branch Correlation

Cliff Young and Michael D. Smith

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Harvard University, Cambridge, MA 02138

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Exploit branch correlation without additional hardware like the global register and pattern history table

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Improving Semi-static Branch Prediction by Code Replication

Andreas Krall
Institut für Computersprachen
Technische Universität Wien
Argentinierstraße 8
A-1040 Wien
`andi@mips.complang.tuwien.ac.at`

Create a compiler transformation based on profile information that encodes the branch history information in the program counter via basic block duplication

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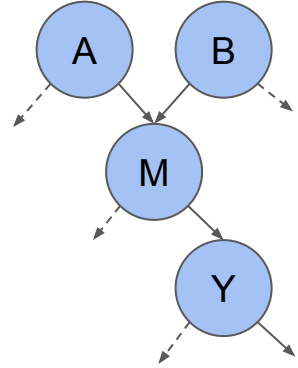
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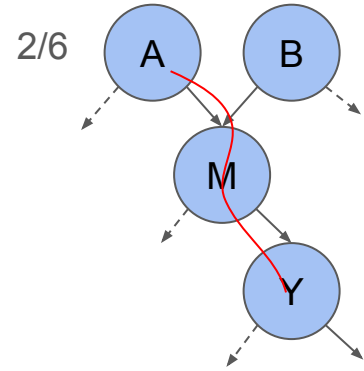
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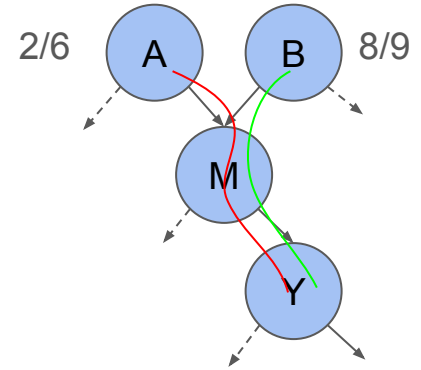
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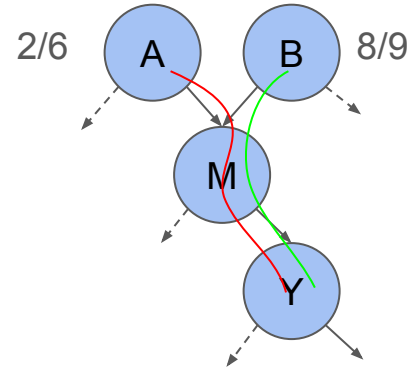
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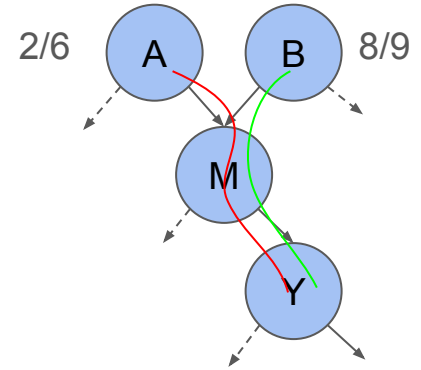
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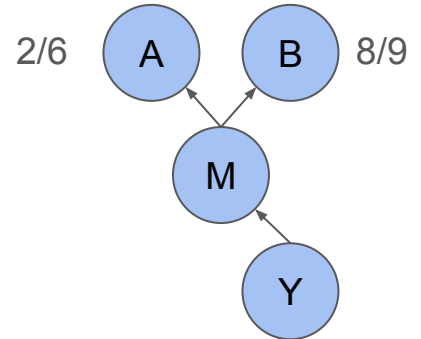
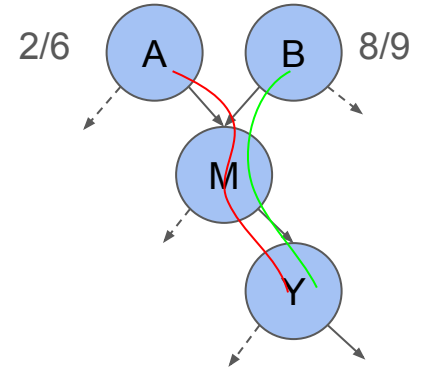
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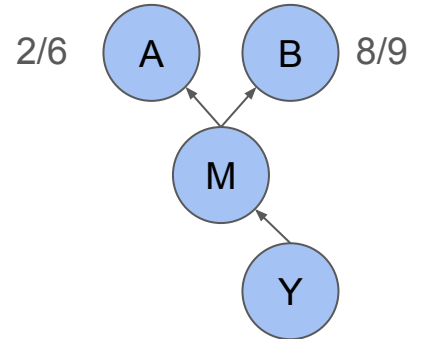
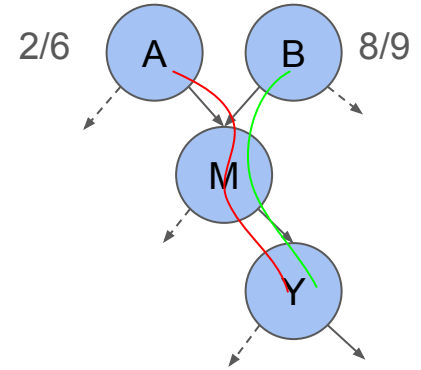
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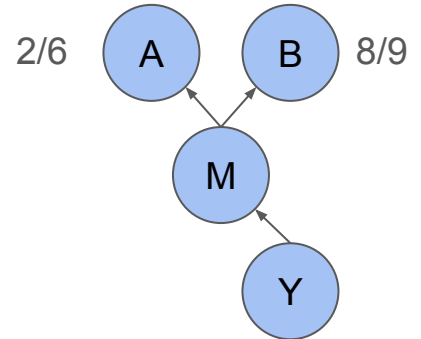
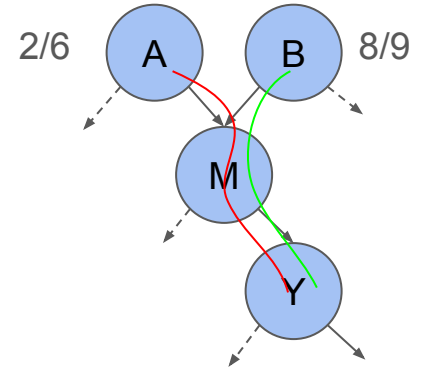
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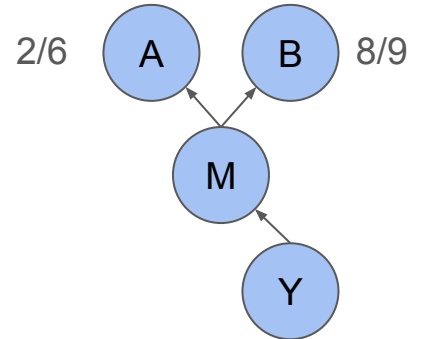
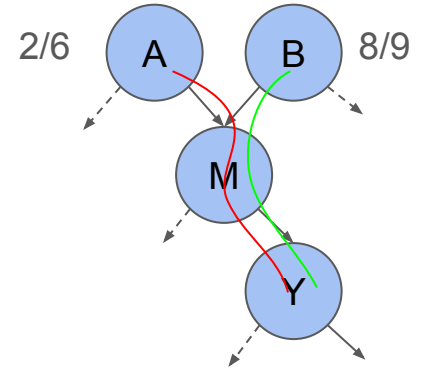
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 - Prune nodes while maximizing prediction accuracy



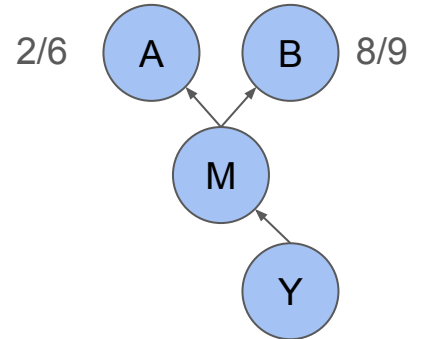
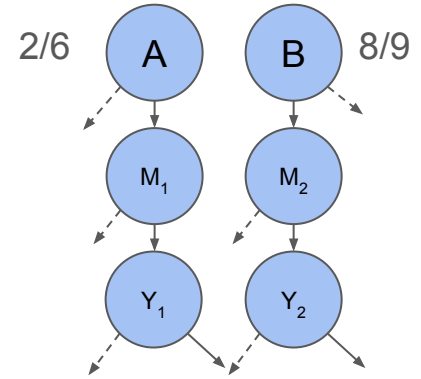
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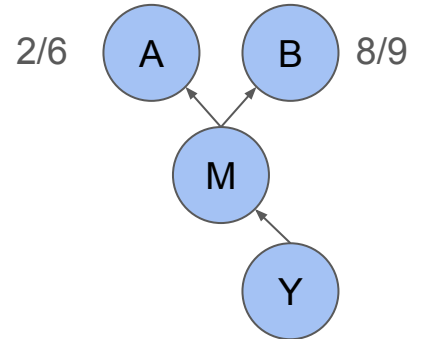
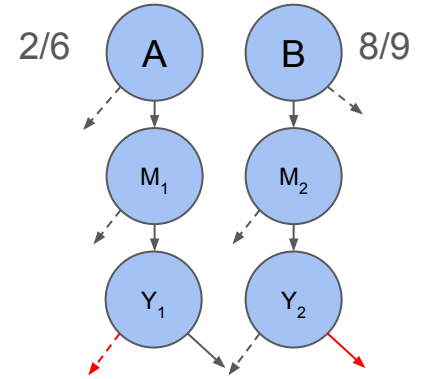
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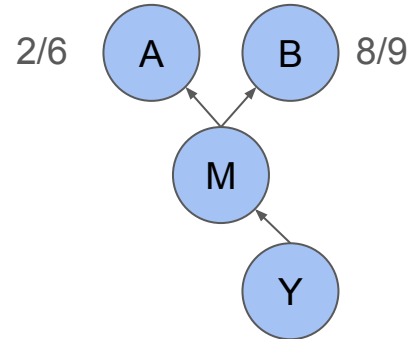
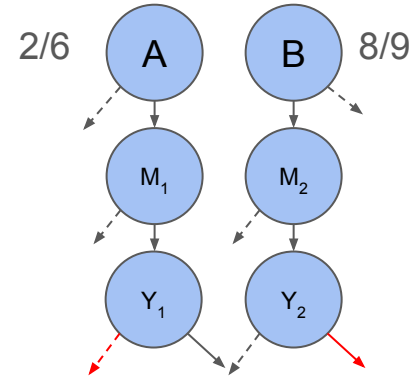
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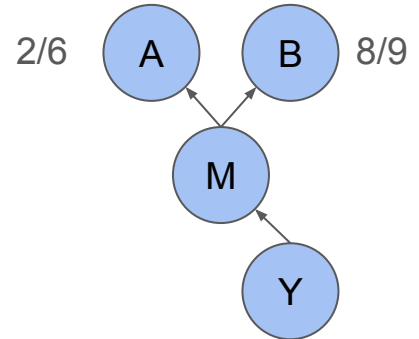
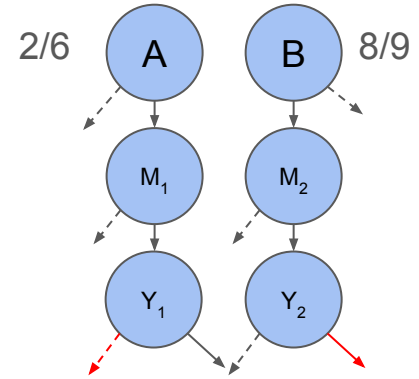
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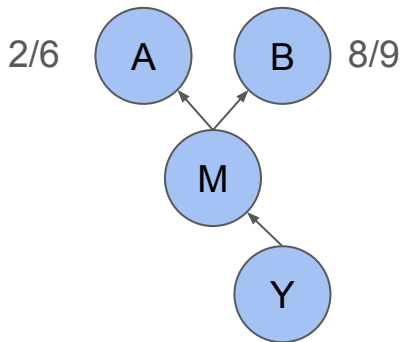
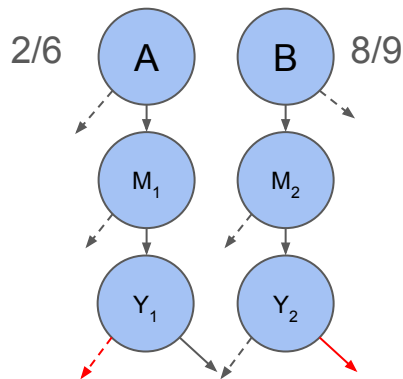
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- Layout the transformed code
 - Avoid increasing the dynamic instruction count



Profile Guided Code Positioning

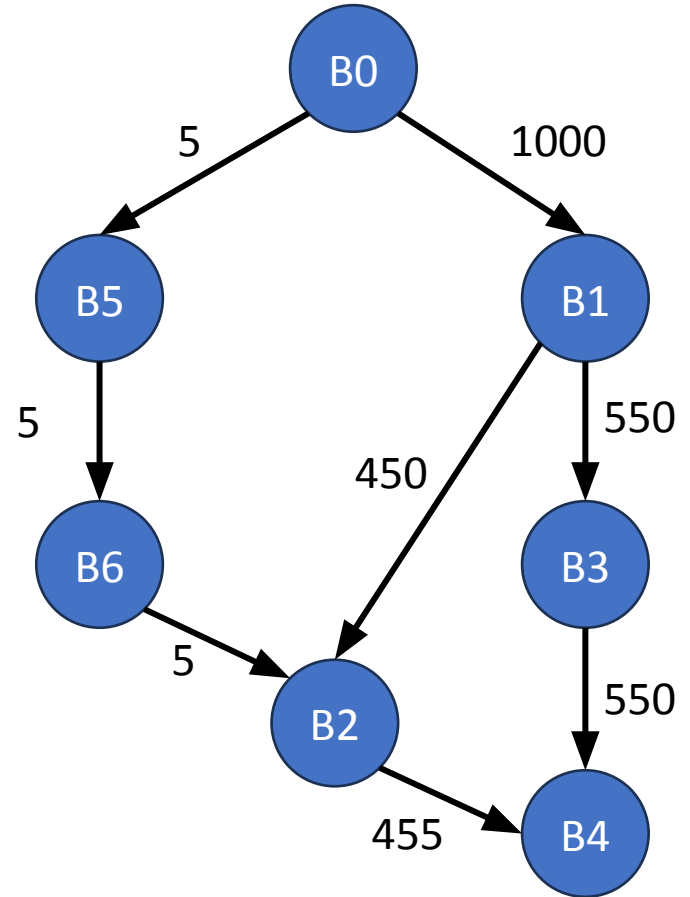
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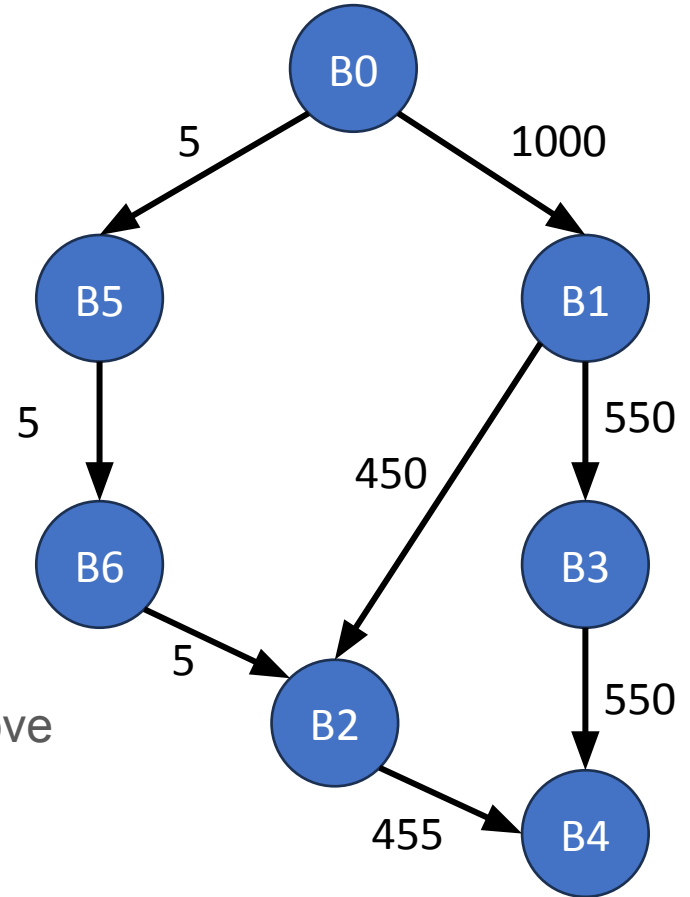


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Reposition basic blocks using profile data to improve
static branch prediction for a PA-RISC CPU



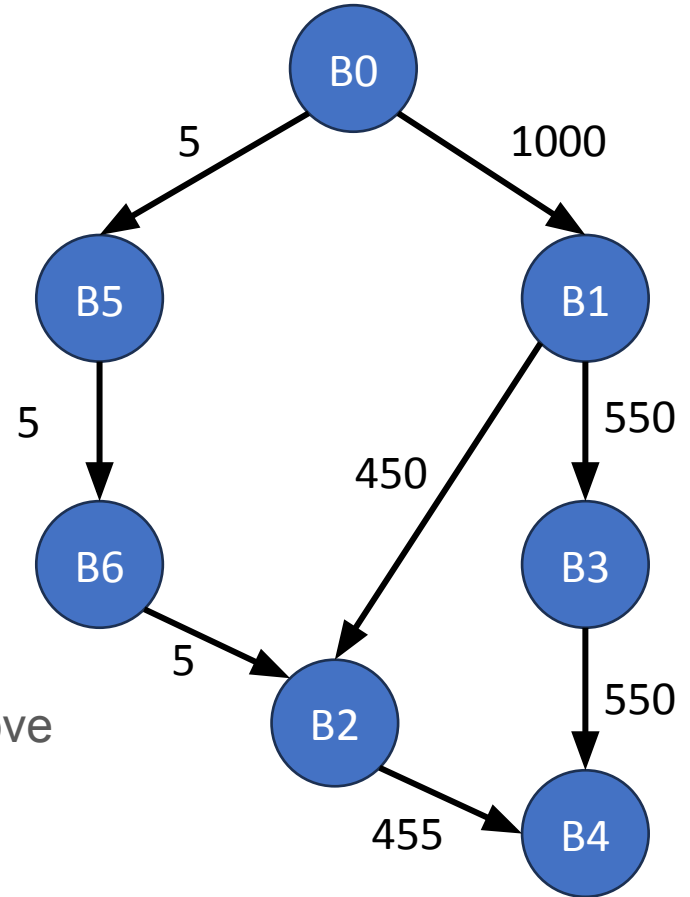
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- Backward branches taken



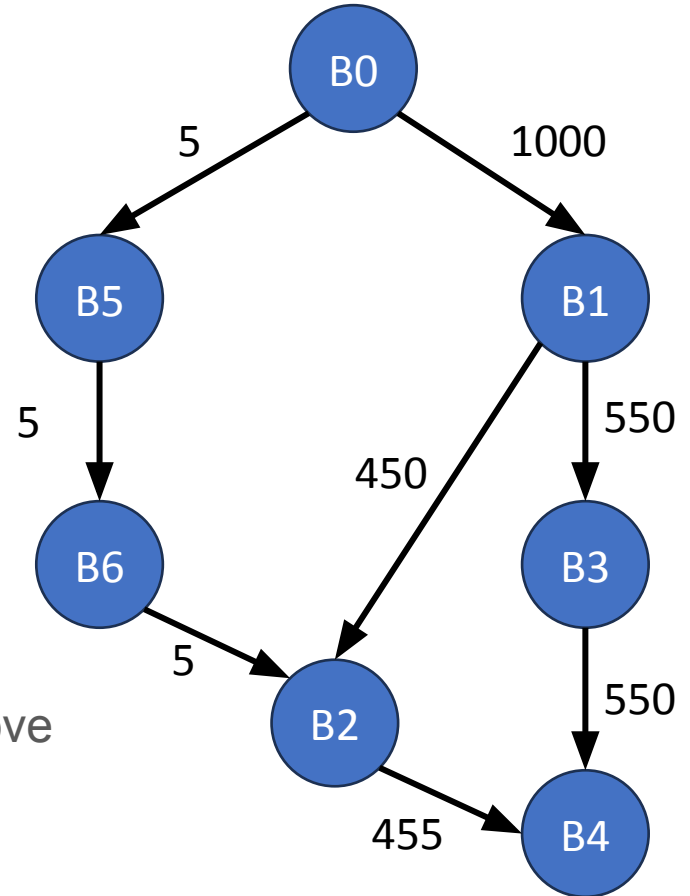
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Reposition basic blocks using profile data to improve static branch prediction for a PA-RISC CPU

- Backward branches taken
- Forward branches not taken



Reducing the Cost of Branches

Scott McFarling and John Hennessy
Computer Systems Laboratory
Stanford University

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Introduces the concept of the delayed branch

McFarling & Hennessey (1986)

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 - After branch / From target: must be safe to execute the instruction whether the branch is taken or not
 - Beneficial if the instruction is along the correct path
- Difficult to find safe instructions to fill the “delay” slots

McFarling & Hennessey (1986)

Delayed branch with squashing

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McFarling & Hennessey (1986)

Delayed branch with squashing

- Use a bit to indicate the predicted direction
 - Delay slots filled by instructions from that direction
 - Squash when incorrect
- Use a bit to specify if squashing is needed on a misprediction
 - Machine does not need to squash if the compiler can fill the delay slots with safe instructions

Branch Prediction For Free

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- Program-based static branch prediction

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- Program-based static branch prediction
- Uses natural loop analysis to predict loop branches

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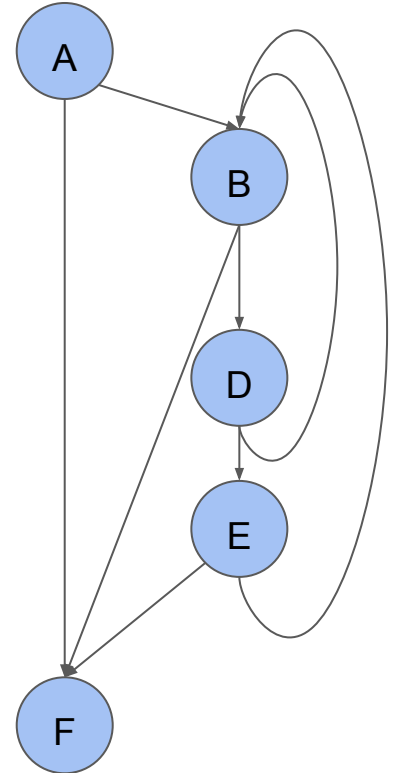
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- Program-based static branch prediction
- Uses natural loop analysis to predict loop branches
- Uses heuristics to predict non-loop branches

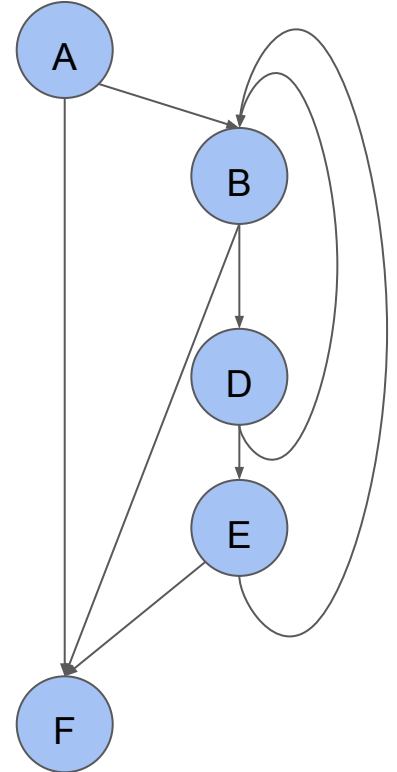
Ball & Larus (1993): Predicting loop branches

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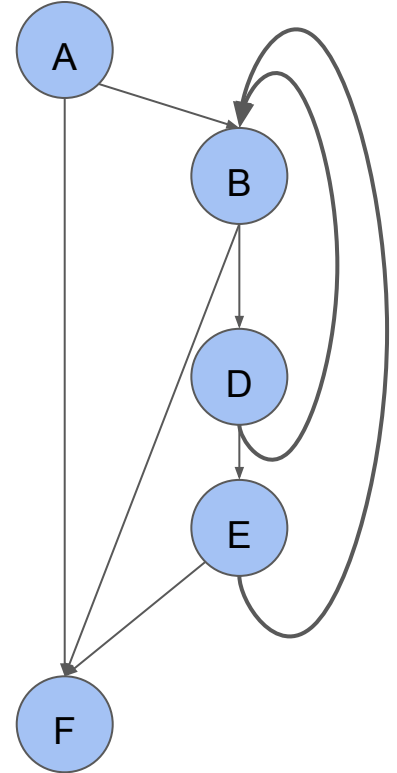
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- Find back-edges and natural loops in the CFG



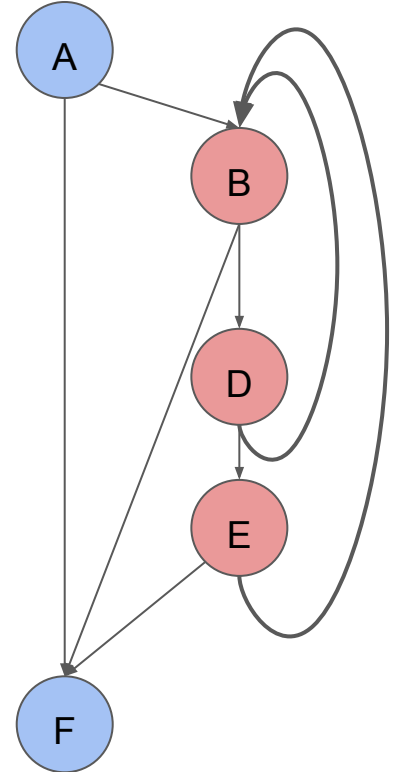
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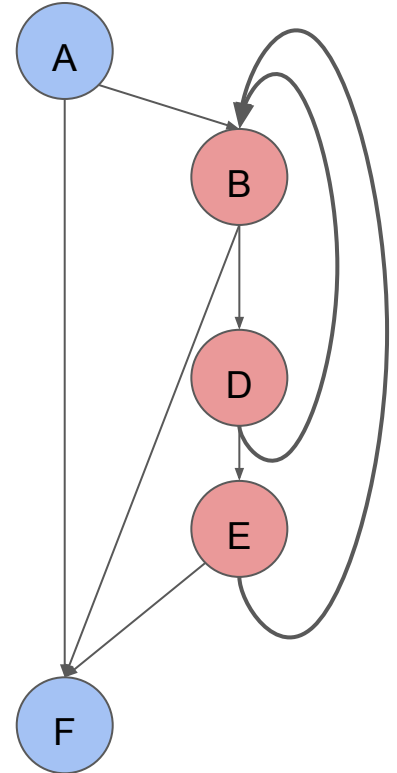
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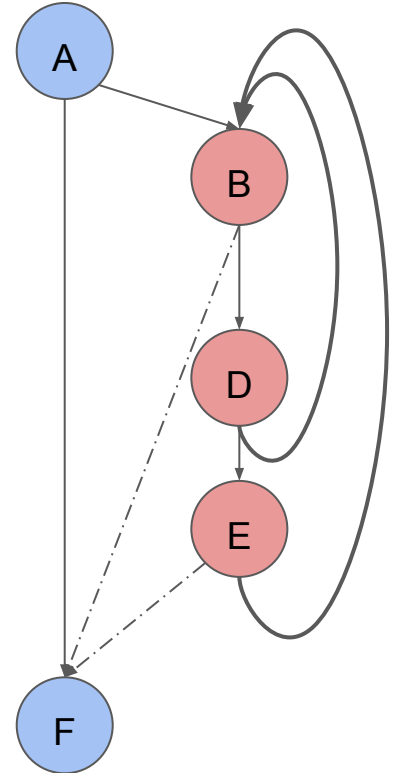
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- Find back-edges and natural loops in the CFG
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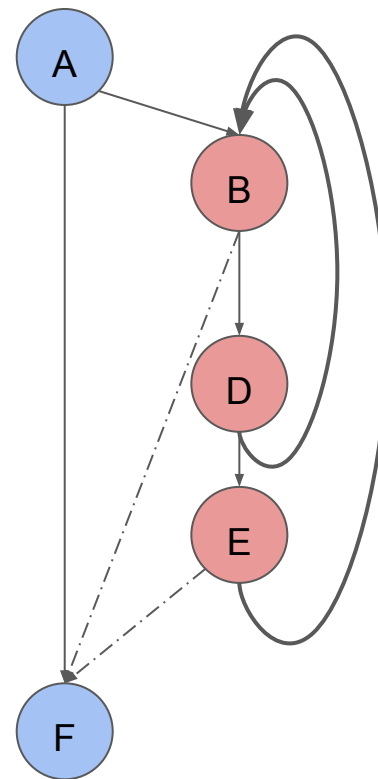
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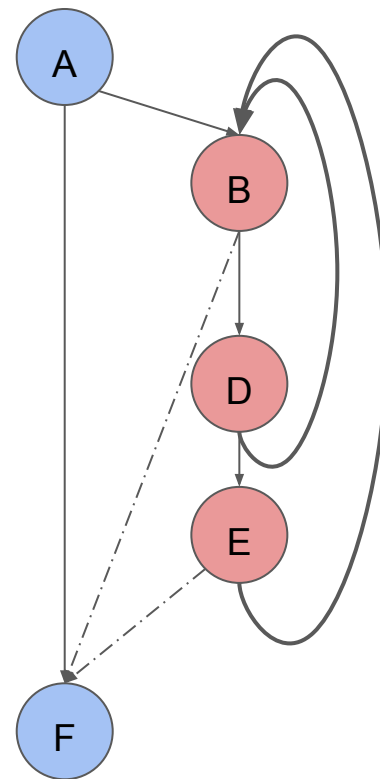
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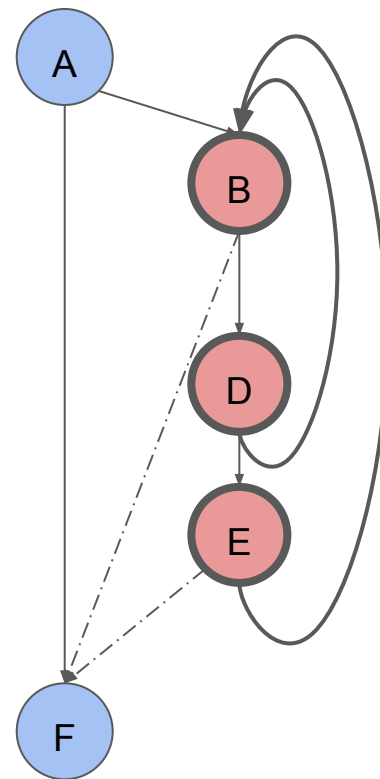
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 - Either of its outgoing edges is an exit-edge or back-edge



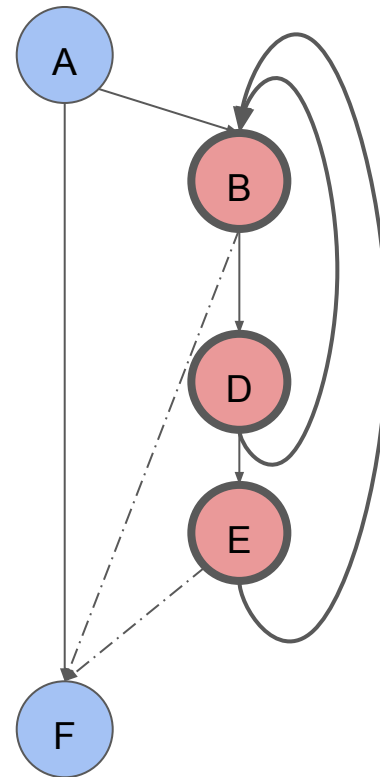
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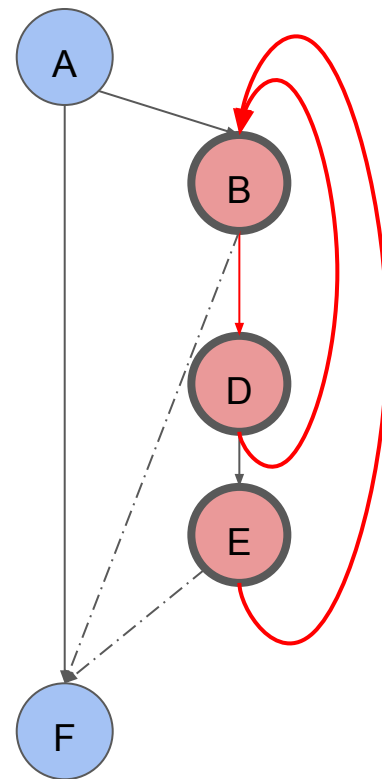
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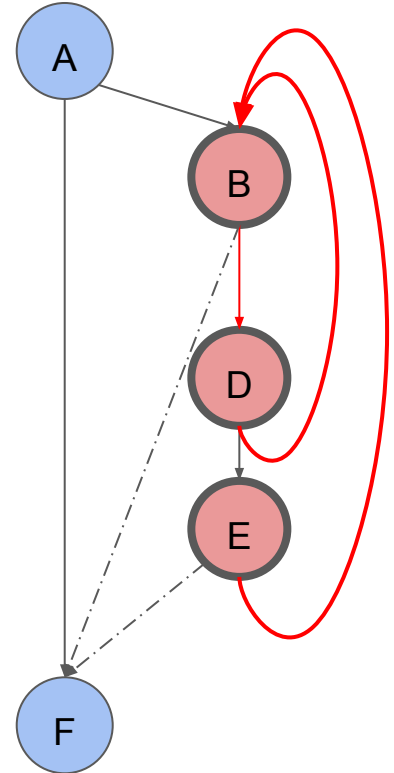
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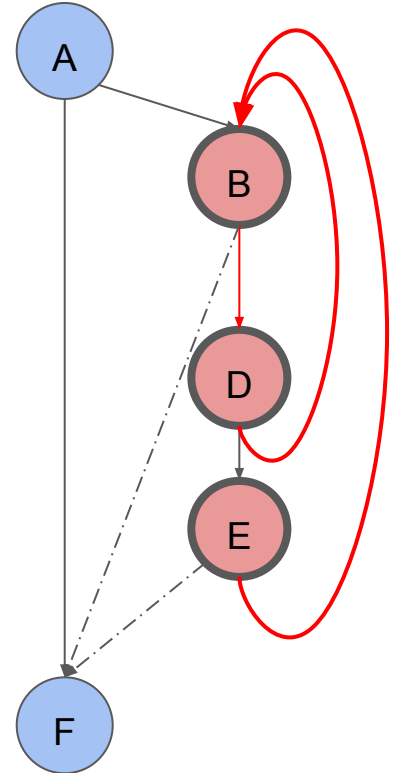
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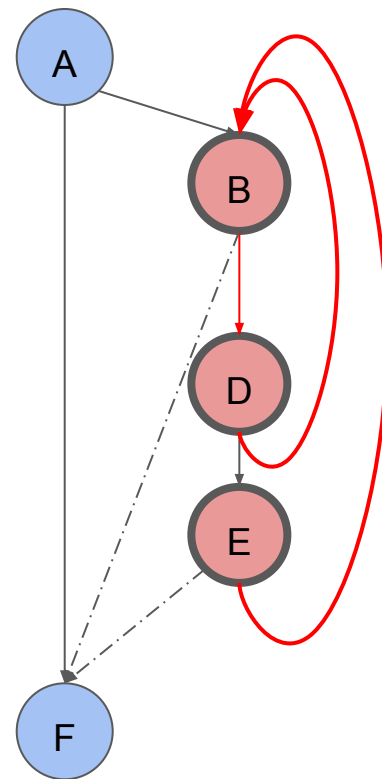
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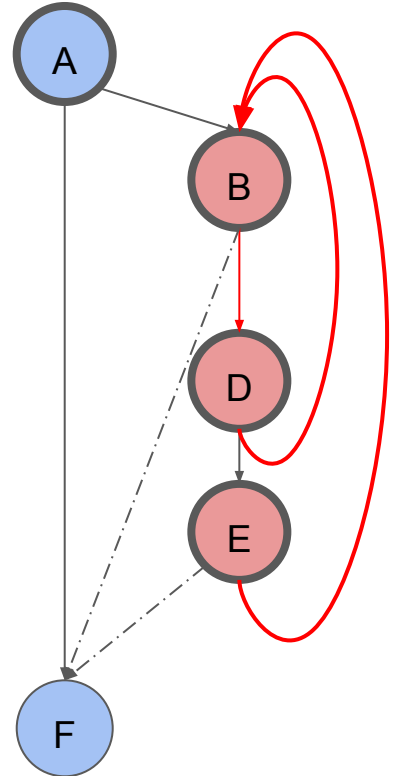
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Ball & Larus (1993): Predicting non-loop branches

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1. Opcode Heuristic

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Many programs use negative integers to denote error values

Floating point numbers are rarely equal

Ball & Larus (1993): Predicting non-loop branches

2. Loop Heuristic

Ball & Larus (1993): Predicting non-loop branches

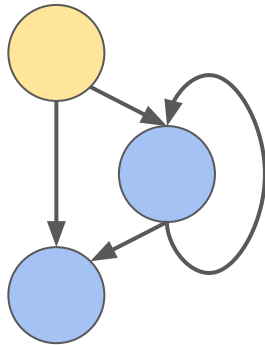
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- Prefer branch direction to successor block that is a loop header

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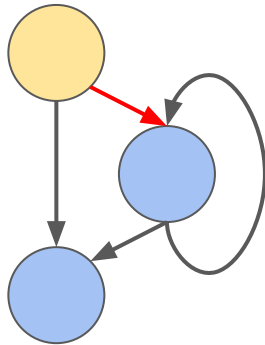
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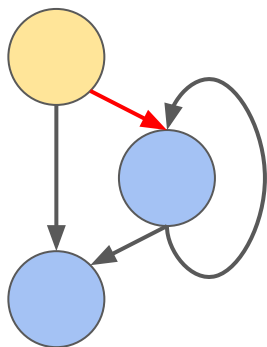


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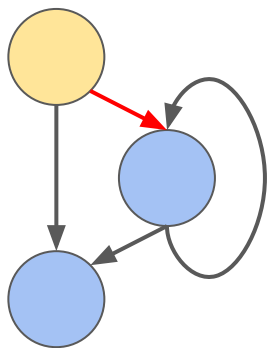
```
while(i < n) {  
    ...  
}
```



Ball & Larus (1993): Predicting non-loop branches

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- Prefer branch direction to successor block that is a loop header



```
while(i < n) {  
    ...  
}
```



```
if (i >= n) goto skip  
body:  
    ...  
    if (i < n) goto body  
skip:
```

Ball & Larus (1993): Predicting non-loop branches

3. Call Heuristic

Ball & Larus (1993): Predicting non-loop branches

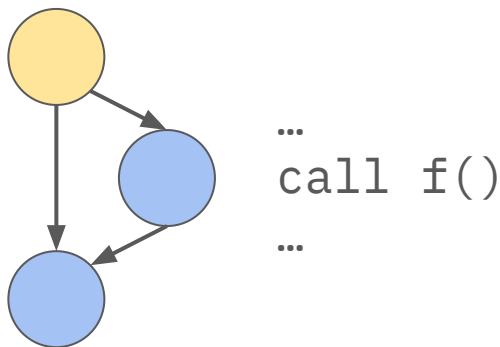
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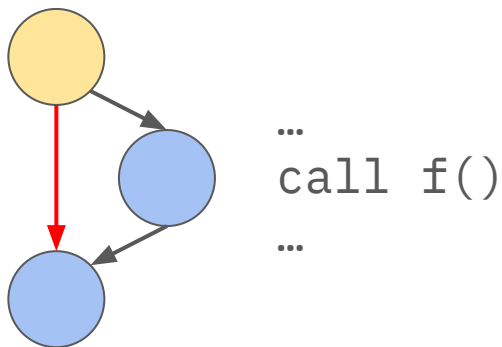
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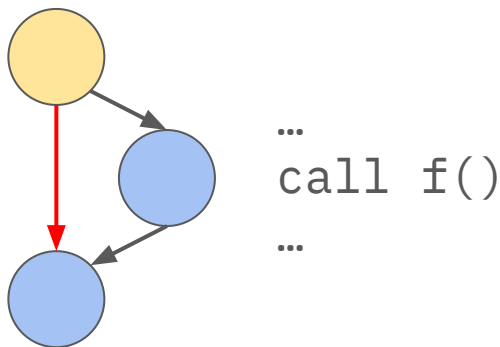


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Many conditional calls are to handle rare situations



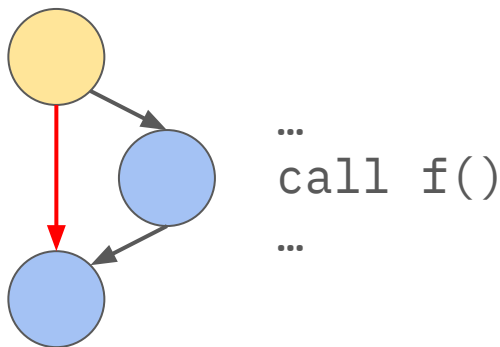
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Many conditional calls are to handle rare situations

eg: printing output



Ball & Larus (1993): Predicting non-loop branches

4. Return Heuristic

Ball & Larus (1993): Predicting non-loop branches

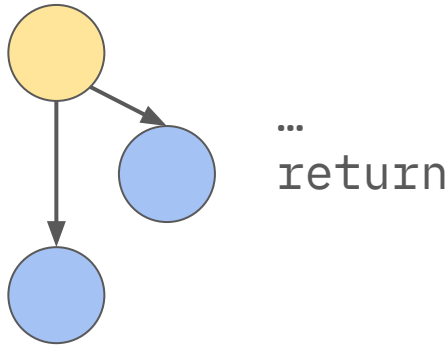
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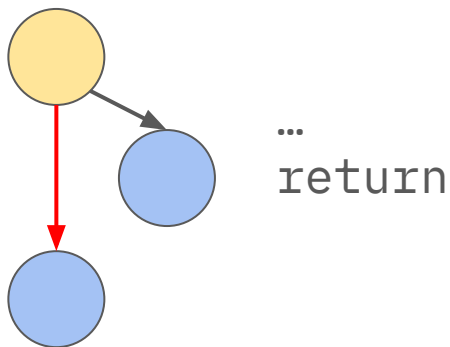
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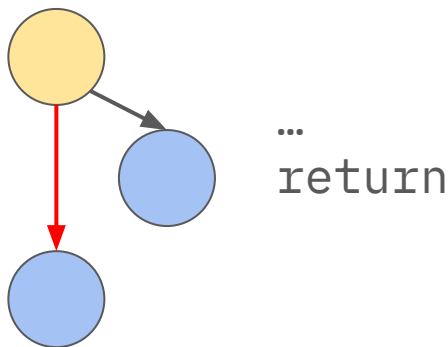


Ball & Larus (1993): Predicting non-loop branches

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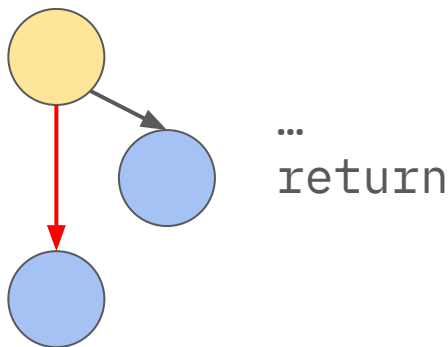
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Ball & Larus (1993): Predicting non-loop branches

4. Return Heuristic

- Prefer branch direction to successor block that does **not** contain a return



*Many conditional returns
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eg: base case in recursion

Ball & Larus (1993): Predicting non-loop branches

5. Guard Heuristic

Ball & Larus (1993): Predicting non-loop branches

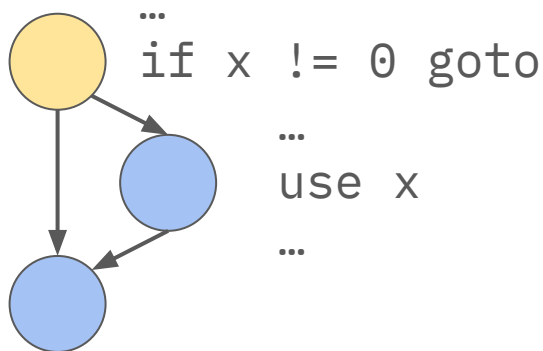
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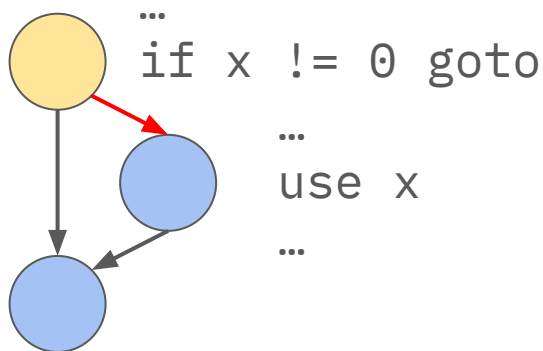
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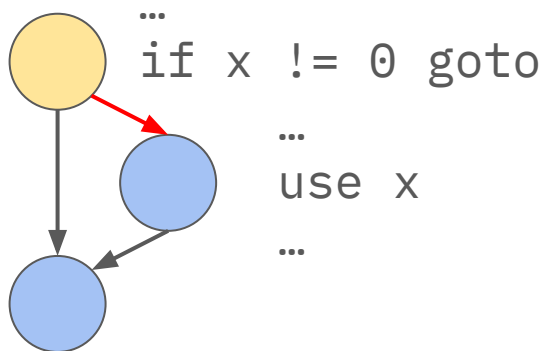


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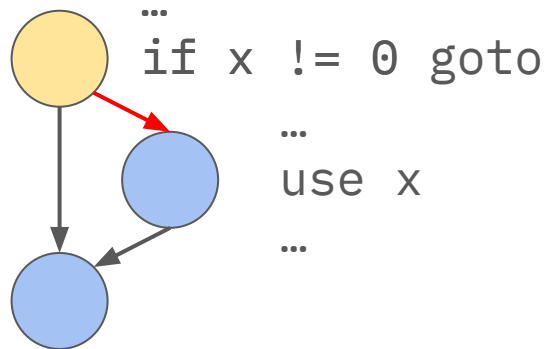
Many guard conditionals usually allow the guarded value to flow to its use



Ball & Larus (1993): Predicting non-loop branches

5. Guard Heuristic

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Many guard conditionals usually allow the guarded value to flow to its use

eg: guarding for existence

Ball & Larus (1993): Predicting non-loop branches

6. Store Heuristic

Ball & Larus (1993): Predicting non-loop branches

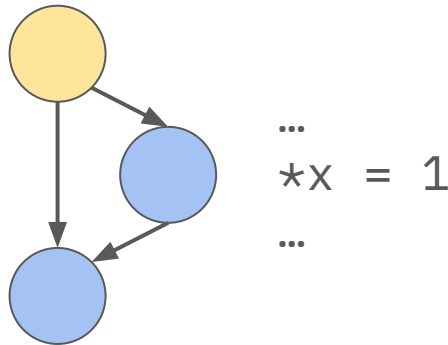
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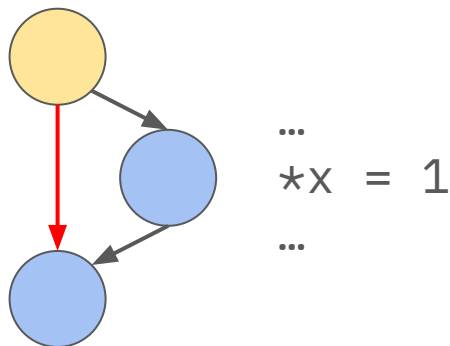
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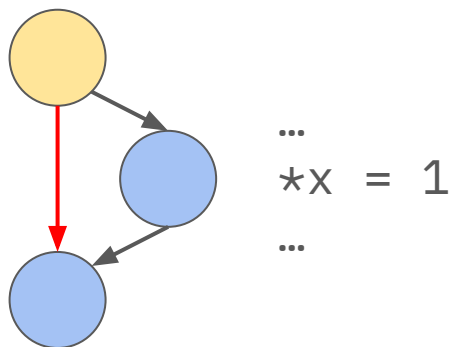


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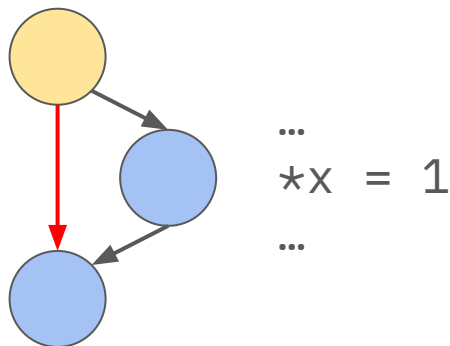
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Ball & Larus (1993): Predicting non-loop branches

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Many conditional stores are to handle rare situations

eg: updating a maximum

Ball & Larus (1993): Predicting non-loop branches

7. Point Heuristic

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- Predict pointer comparisons as false

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Ball & Larus (1993): Predicting non-loop branches

7. Point Heuristic

Both cases are rarely true

- Predict pointer comparisons as false
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Ball & Larus (1993): Predicting non-loop branches

1. Opcode
2. Loop
3. Call
4. Return
5. Guard
6. Store
7. Point

Ball & Larus (1993): Predicting non-loop branches

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- More than 1 heuristic can apply to a branch

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 - **Point, Call, Opcode, Return, Store, Loop, Guard**

Dynamic Branch Prediction

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Reducing Branch Costs via Branch Alignment

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Department of Computer Science

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- Use PH's algorithm to minimize the number of taken branches by placing the hot path in a straight line of fall through execution

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- Use PH's algorithm to minimize the number of taken branches by placing the hot path in a straight line of fall through execution
- Show that branch alignment improves dynamic branch prediction accuracy

Code Placement for Improving Dynamic Branch Prediction Accuracy

Daniel A. Jiménez

Department of Computer Science
Rutgers University
Piscataway, New Jersey, USA

and

Departamento de Arquitectura de Computadores
Universidad Politécnica de Cataluña
Barcelona, Cataluña, Spain

djimenez@cs.rutgers.edu

Jiménez (2005)

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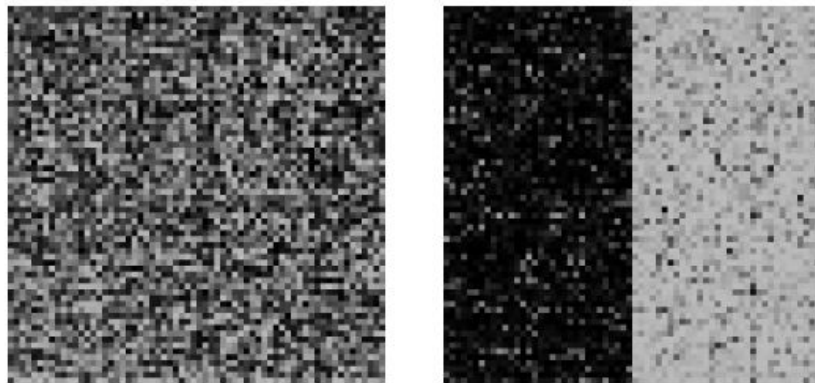


Figure 1. Average PHT entries before and after compiler-based alignment.

Branchless Code Generation for Modern Processor Architectures

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No need to predict a branch that isn't there

Angelou et al. (2021)

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- Remove branches in a program using code transformations

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Angelou et al. (2021)

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- Implemented using the LLVM Framework and MIPS

Thank you :)

References

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