Timely, Efficient, and Accurate Branch Precomputation

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Background

- **Branch mispredictions still limit single-thread performance**
  - Most of these mispredictions come from a small set of problematic branches referred to as "hard-to-predict" (H2P) branches
  - Building extremely large predictors or using state-of-the-art neural networks at best reduces a third of the mispredictions
- **Alternative: Branch Precomputation**
  - Been around for over 25 years
  - Identify H2P branches and instructions in their dependence chains
  - Use the chains to compute H2P branch directions faster than the main thread
  - If the precomputation result arrives **by the time the corresponding branch is fetched**, it is used to override the branch predictor

Branch Precomputation: Prior Work

Key considerations:

accuracy **coverage** **timeliness**

Compiler techniques

- Create a perfectly accurate but heavy-weight helper thread
- Good coverage (>70%)
- Poor timeliness: <20% of precomputation results arrive in-time to override the prediction

Runtime solutions

- Create light-weight dependence chains for specific types of control flows
- Good timeliness: ~70% of precomputation results are timely
- Poor coverage (~30%)

Thus, the tradeoff between coverage and timeliness severely limits performance

A Timely, Efficient, and Accurate Precomputation Thread

We use precomputation results that arrive after the branch is fetched but before it is executed to issue early pipeline flushes

- Enabled by synchronized timestamps provided the thread construction mechanism

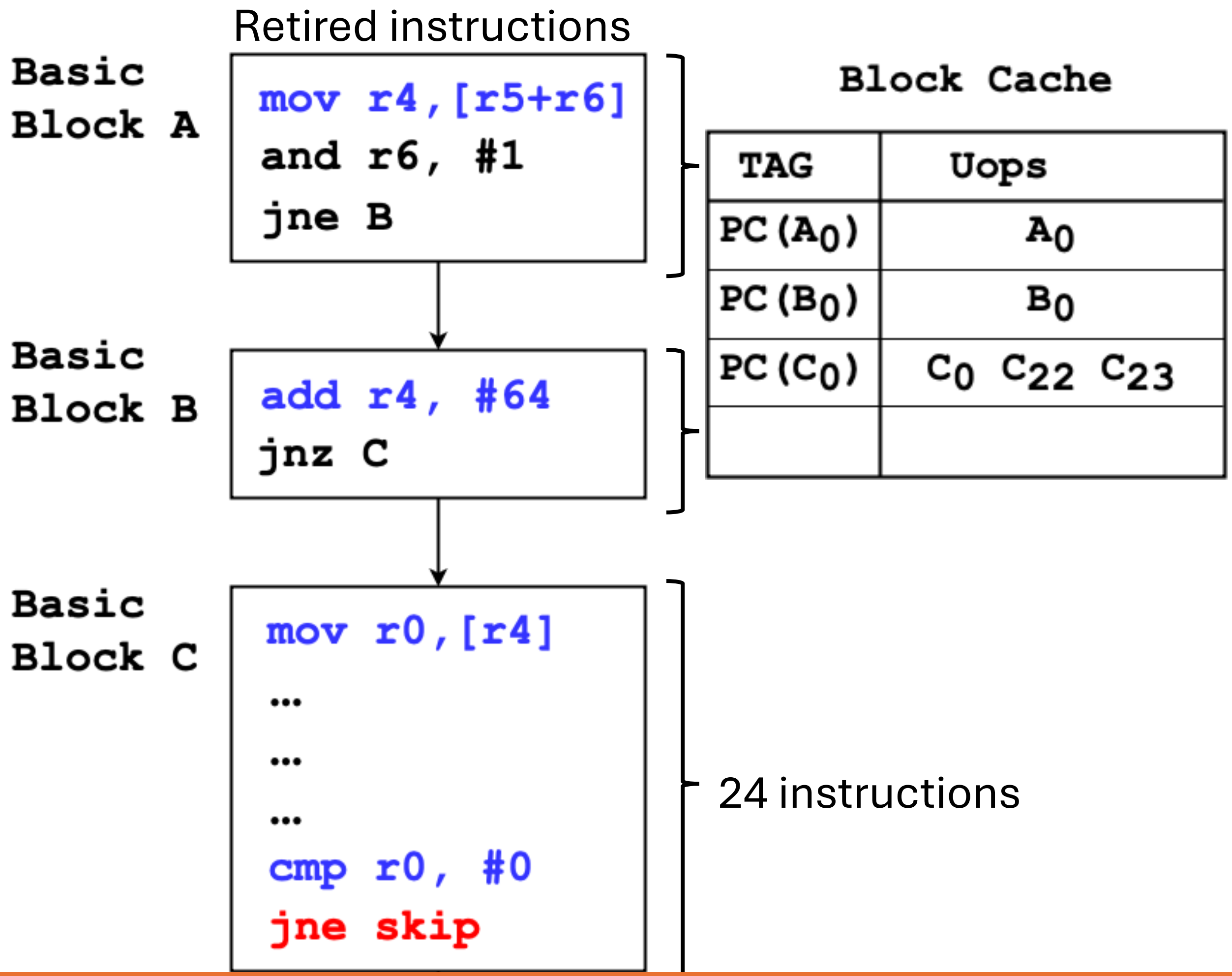
Mechanism for generating highly accurate dependence chains (>99.3%) at runtime for H2P branches

- Improves misprediction coverage without hurting timeliness, traces longer chains

Our precomputation thread can efficiently execute on-core without delaying the main thread significantly

The TEA thread provides a 10.1% performance improvement over a set of SPEC CPU2017 and GAP benchmarks

Identifying H2P Branch Chains

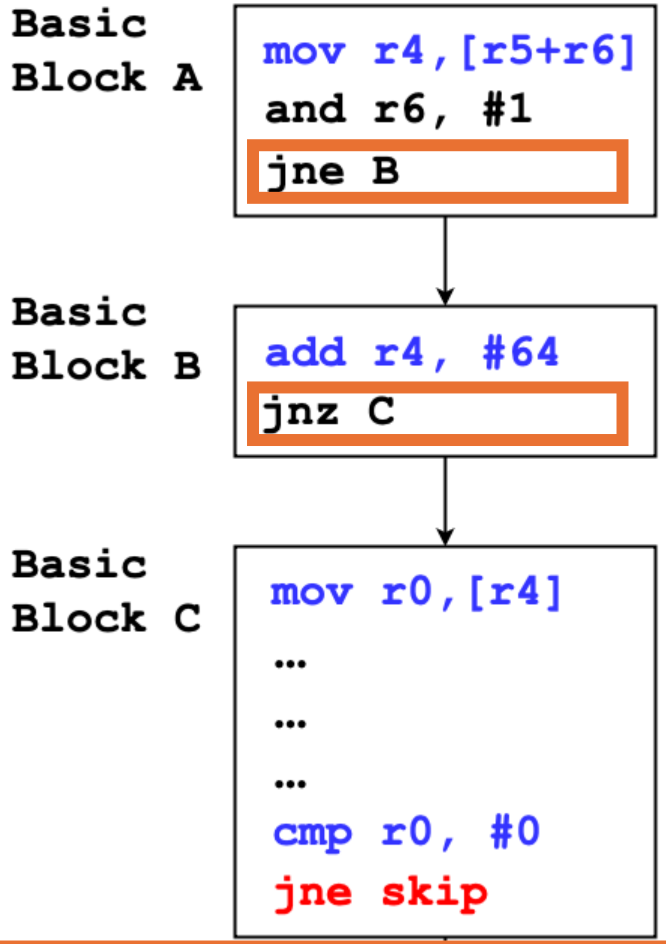


TAG	Uops
PC(A_0)	A_0
PC(B_0)	B_0
PC(C_0)	C_0 C_{22} C_{23}

- After retirement instructions are collected into a Fill Buffer
- Identify frequently mispredicting branches via the H2P Table
- Dependence chain instructions are traced via a Backward Dataflow Walk starting at these branches

Key idea: use the control flow sequence generated by the main branch predictor to stitch together block cache entries and re-construct the dependence chain at fetch time

Constructing the TEA thread



Block Cache

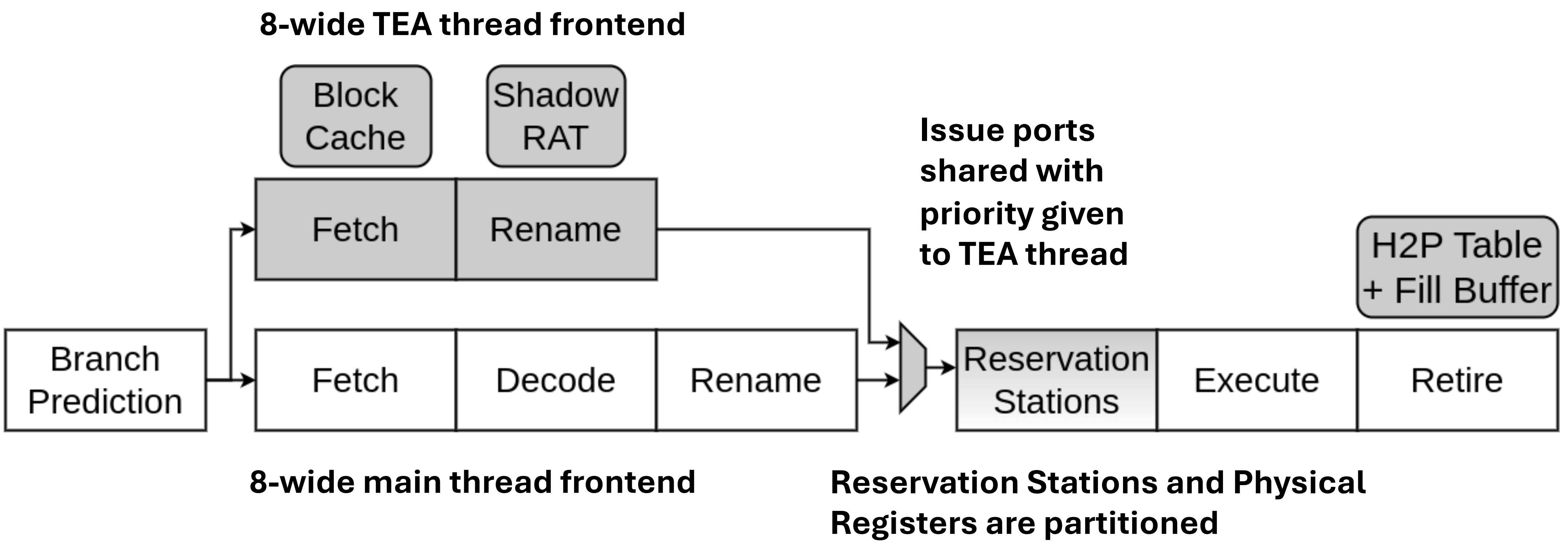
TAG	Uops
PC(A_0)	A_0
PC(B_0)	B_0
PC(C_0)	C_0 C_{22} C_{23}

Branch predictor generates the fetch address sequence:
A (3), B (2), C (24)

Main Thread	TEA Thread
A_0 A_1 A_2	A_0
B_0 B_1	B_0
C_0 … …	C_0 C_{22} C_{23}
… … …	
… C_{22} C_{23}	

- Both threads inherit the same branch IDs from the branch predictor
- Intermediate branches that are not hard-to-predict need not be precomputed

Implementation Overview



1. Faster fetch

2. Prioritized scheduling

3. No backend stalls due to non-dependence chain instructions

Longer dependence chains improve timeliness as it allows the TEA thread to begin earlier

Thank you

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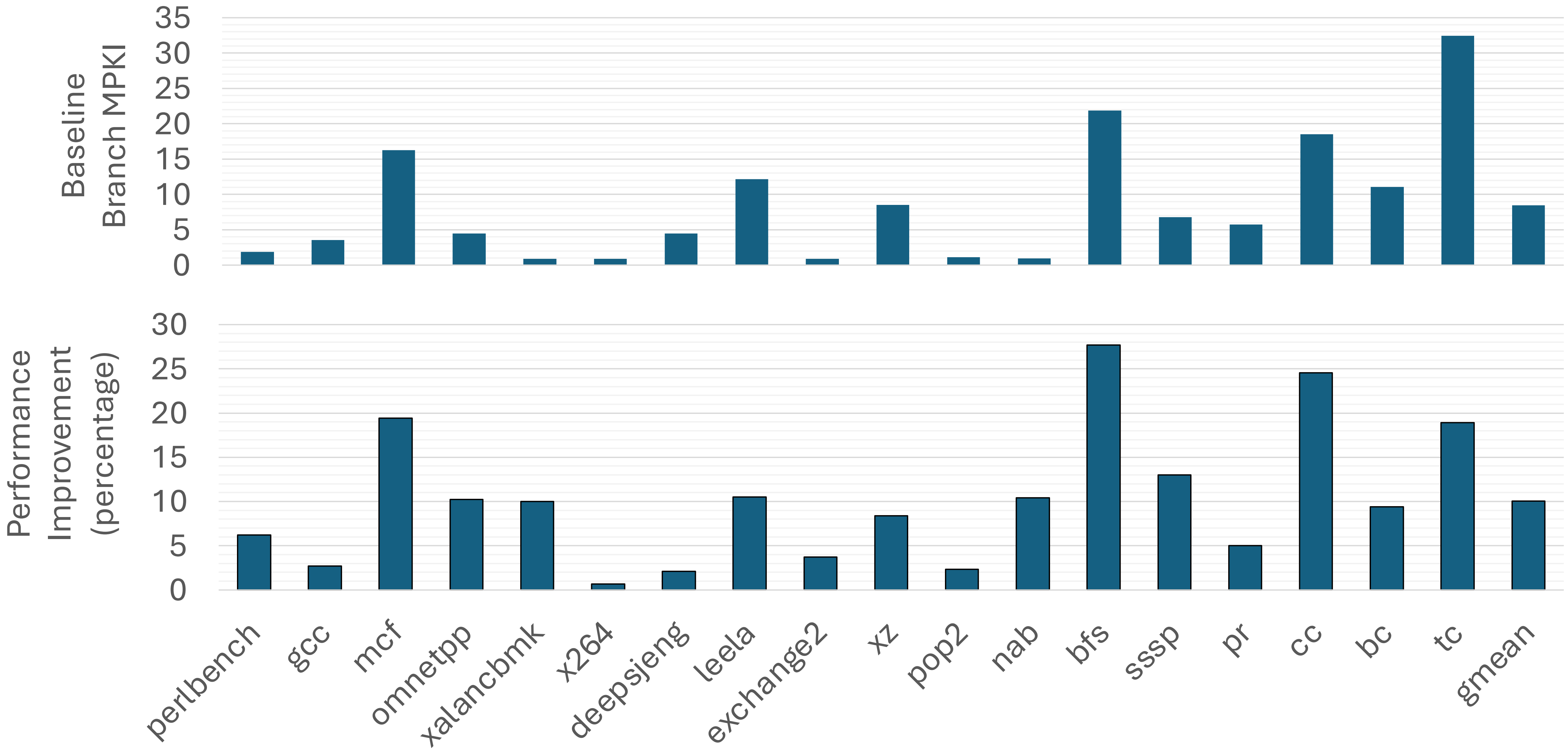
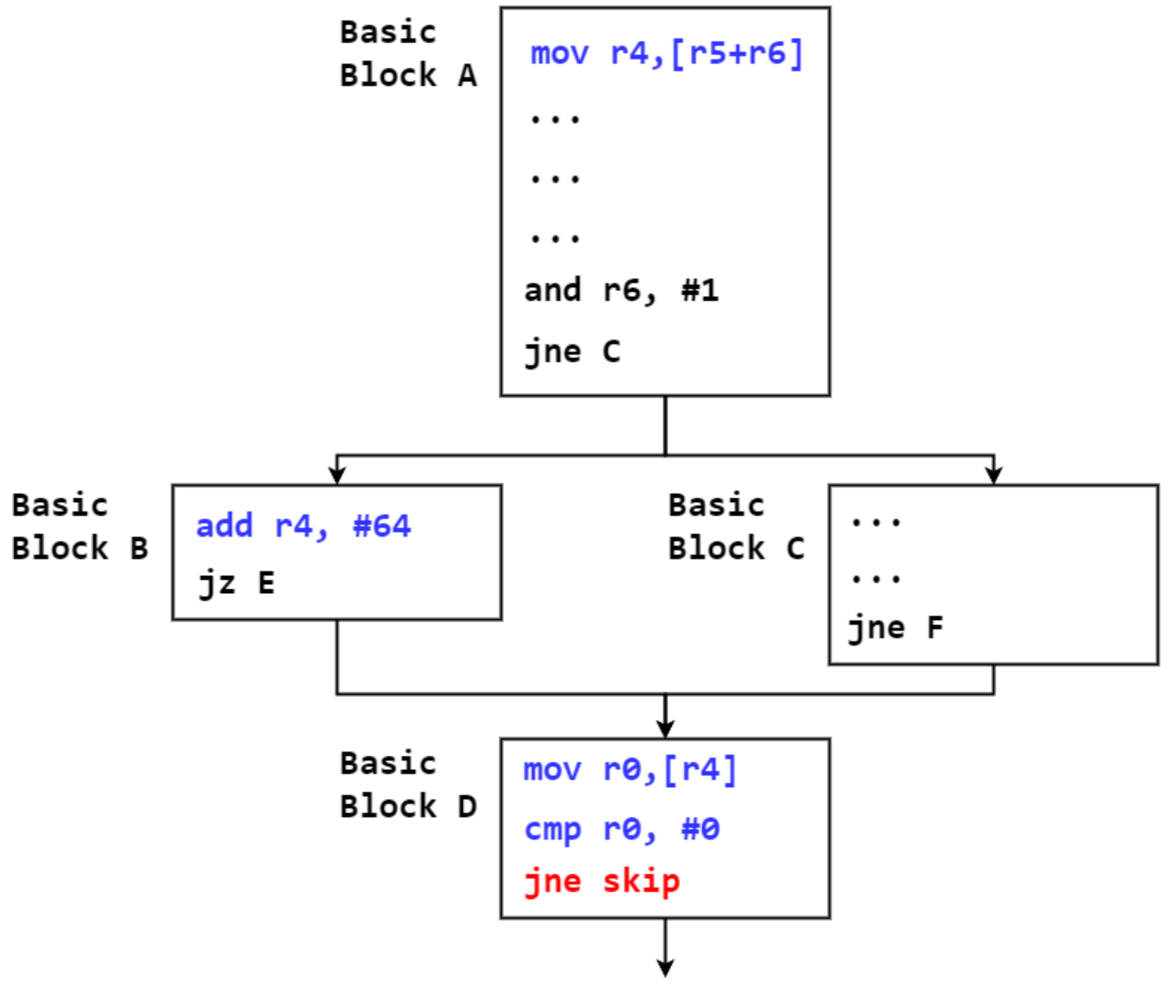
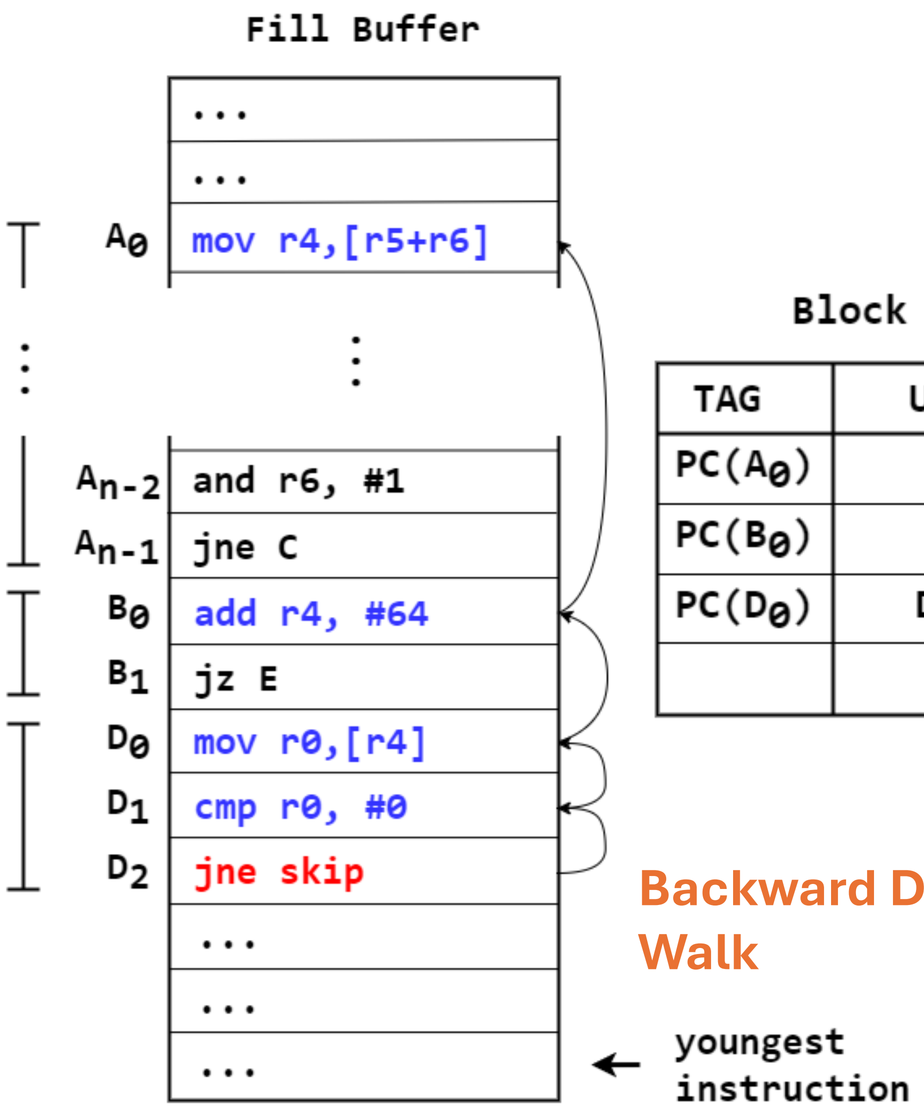
Performance Improvement



Identifying H2P Branch Chains





Block Cache

TAG	Uops
PC(A_0)	A_0
PC(B_0)	B_0
PC(D_0)	D_0 D_1 D_2

Backward Dataflow Walk