Improving the Performance of Object-Oriented Languages with Dynamic Predication of Indirect Jumps

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Motivation

- Polymorphism is a key feature of Object-Oriented Languages
  - Allows modular, extensible, and flexible software design
- Object-Oriented Languages include virtual functions to support polymorphism
  - Dynamically dispatched function calls based on object type
- Virtual functions are usually implemented using indirect jump/call instructions in the ISA
- Other programming constructs are also implemented with indirect jumps/calls: switch statements, jump tables, interface calls

Indirect jumps are becoming more frequent with modern languages

Example from DaCapo *fop* (Java)

- Length
  - LinearCombinationLength
  - PercentLength
  - MixedLength

Length.class:

```
protected void computeValue() {}

public int mvalue() {
    if (!bIsComputed)
        computeValue();
    return millipoints;
}
```

This indirect call is hard to predict

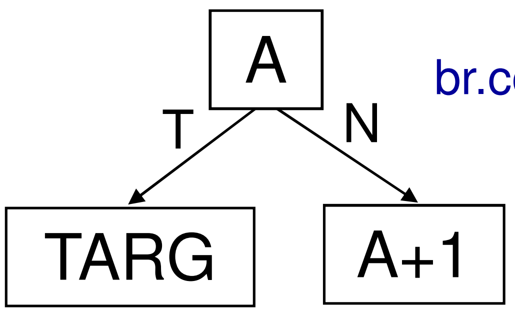
LinearCombinationLength.class:

```
protected void computeValue() {
    // …
    setComputedValue(result);
}
```

PercentLength.class:

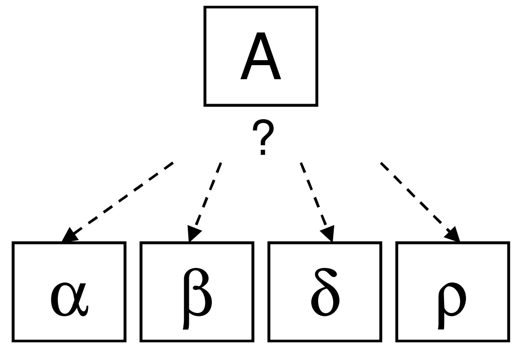
```
protected void computeValue() {
    // …
    setComputedValue(result1);
}
```

Predicting Direct Branches vs. Indirect Jumps



br.cond TARGET

Conditional (Direct) Branch



R1 = MEM[R2]
branch R1

Indirect Jump

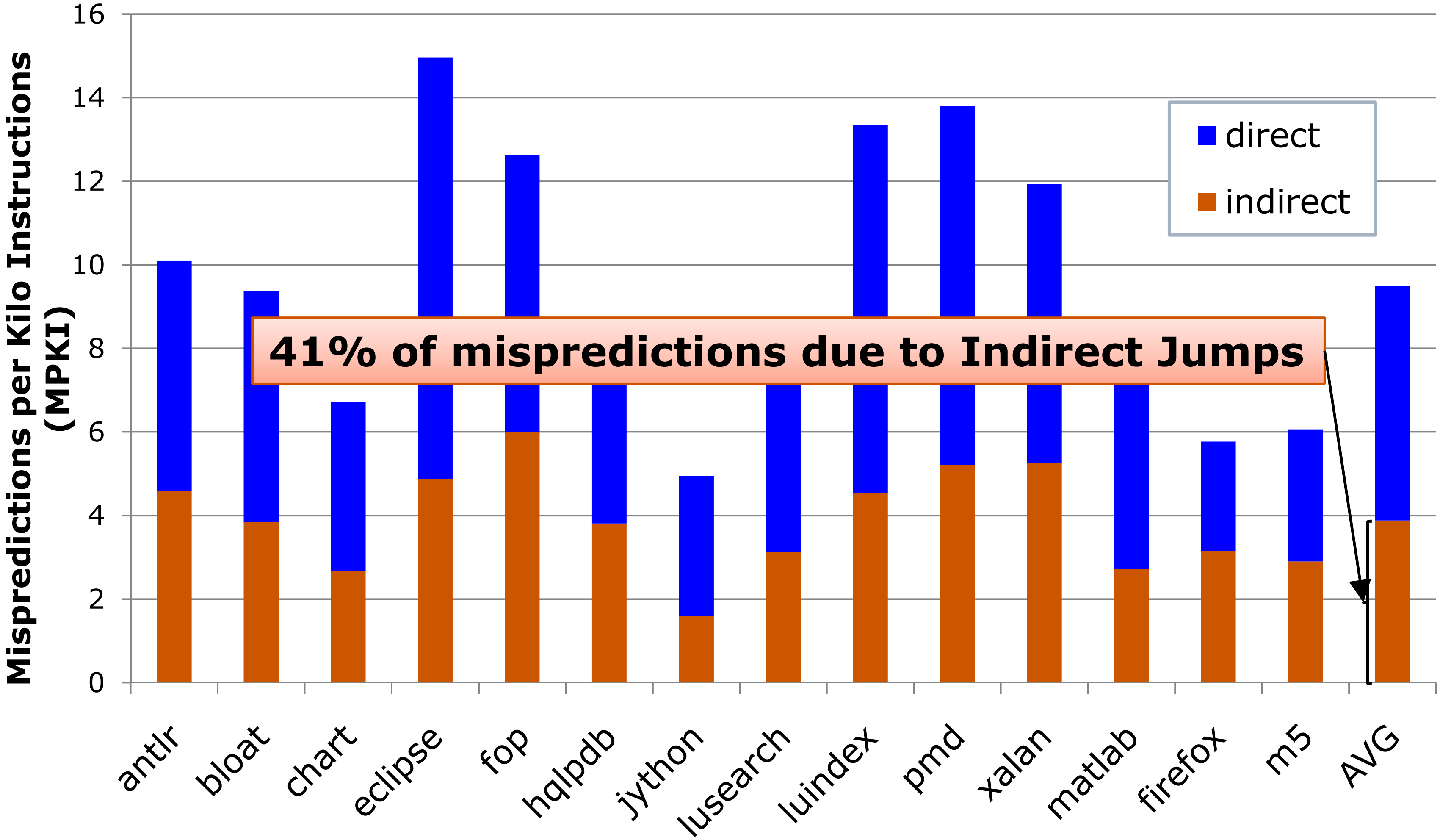
Indirect jumps:

- Multiple target addresses → More difficult to predict than conditional (direct) branches
- Can degrade performance

The Problem

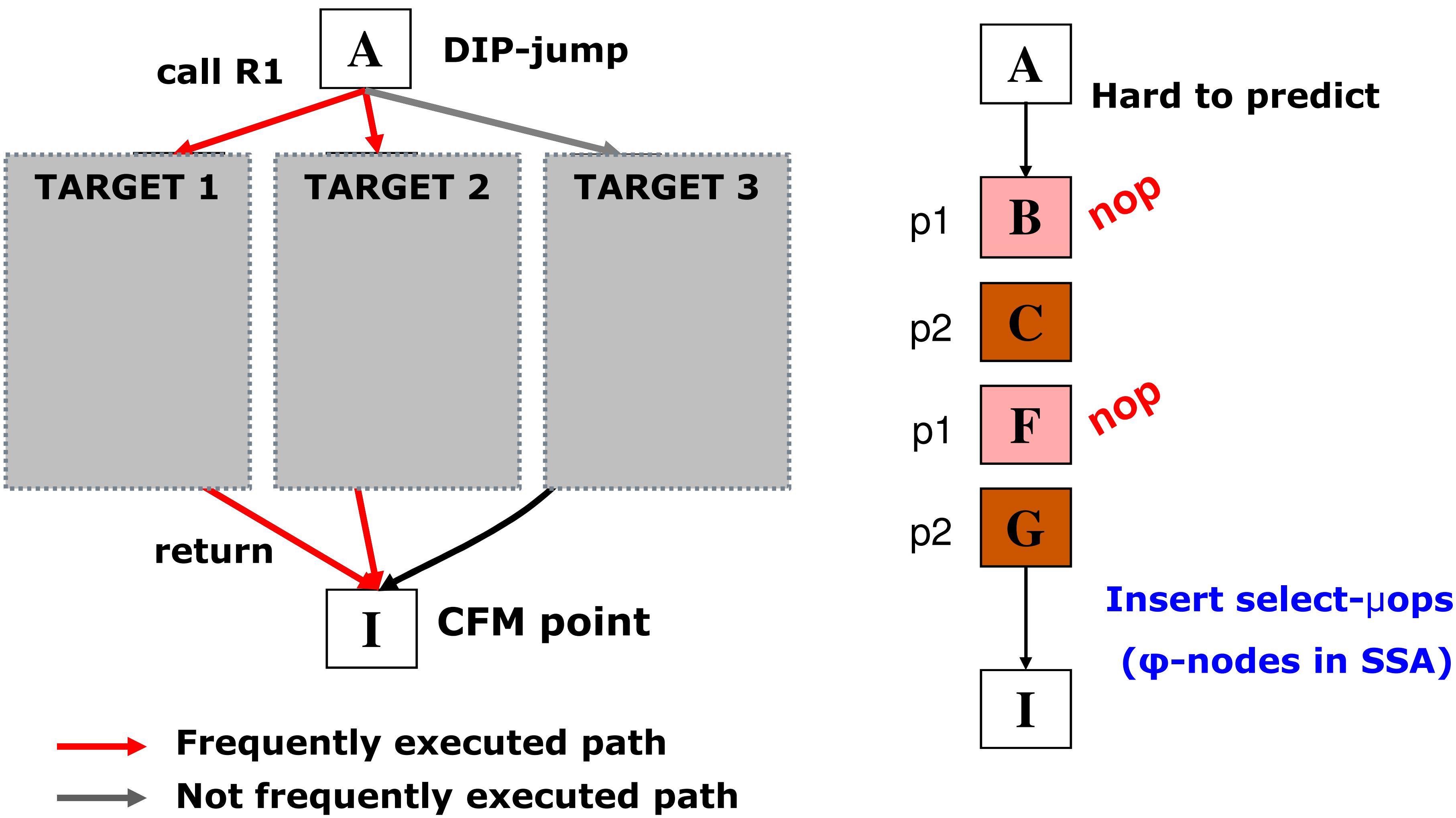
- Most processors predict using the BTB:
  target of indirect jump = target in previous execution
  - Stores only one target per jump
    (already done for conditional branches)
  - Inaccurate
    - Indirect jumps usually switch between multiple targets
    - ~50% of indirect jumps are mispredicted
- Most history-based indirect jump target predictors add large hardware resources for multiple targets

Indirect Jump Mispredictions



Data from Intel Core2 Duo processor

Dynamic Indirect Jump Predication (DIP)



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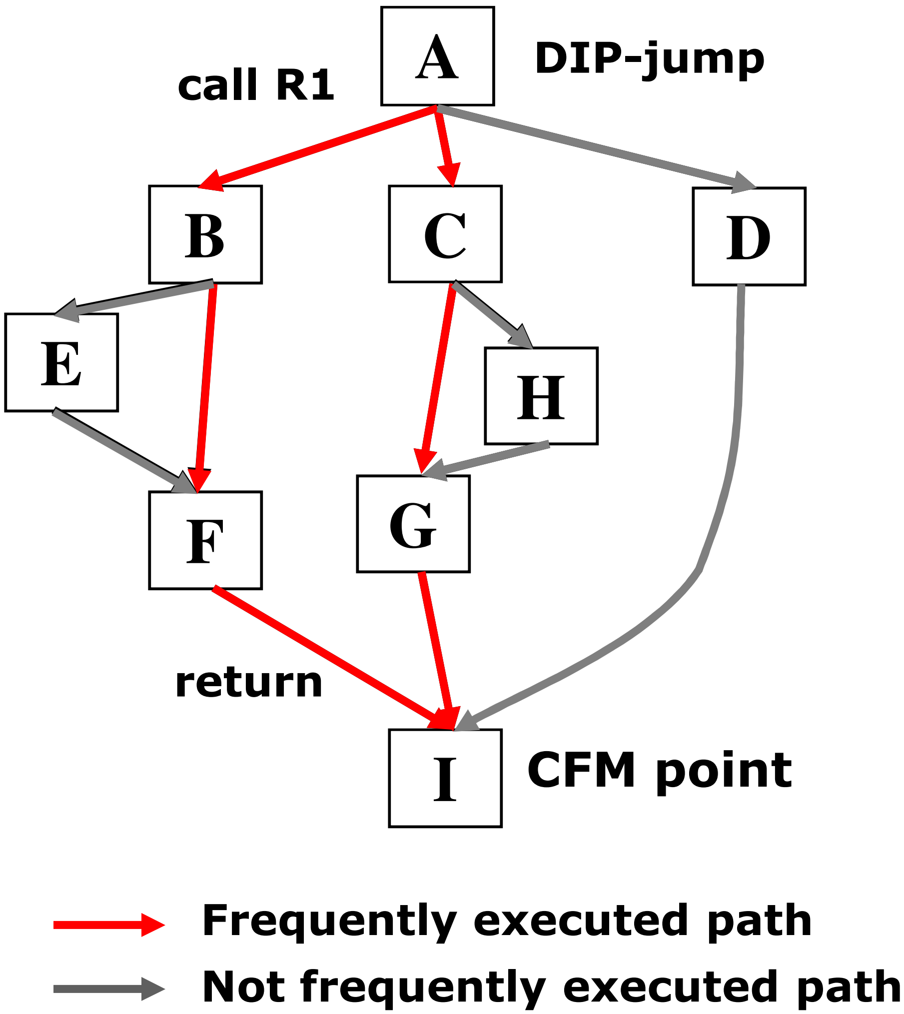
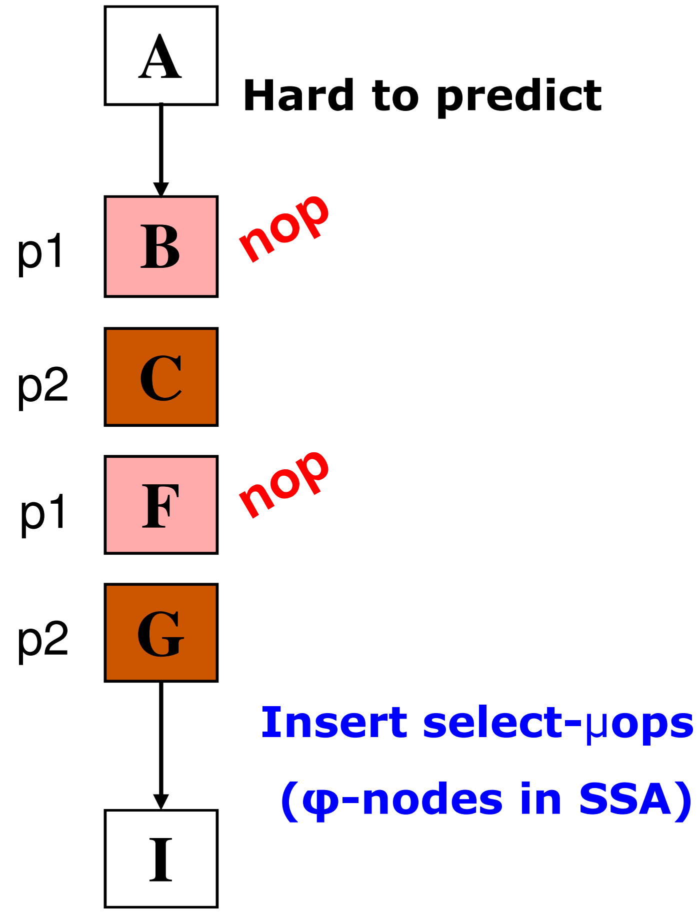


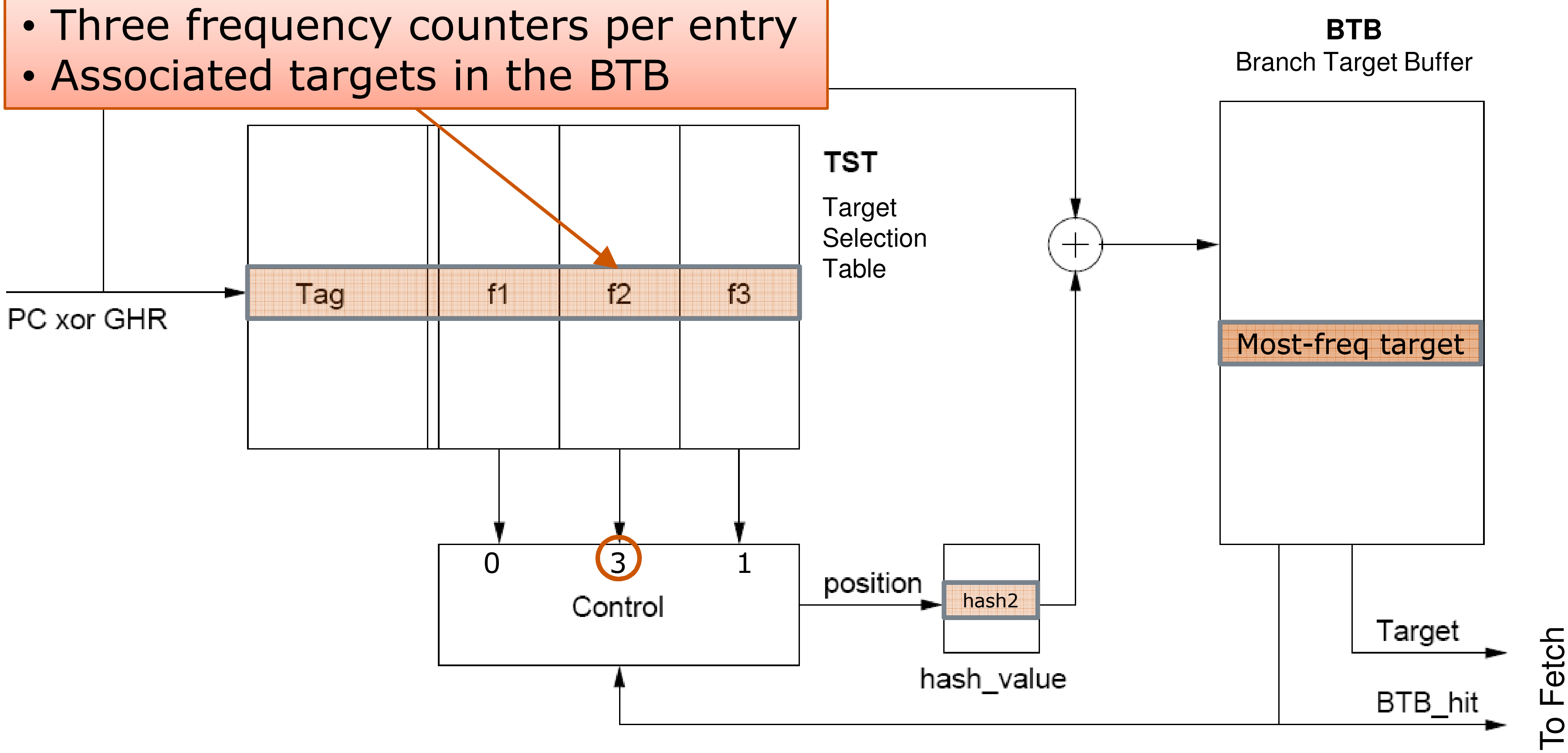


Dynamic Predication of Indirect Jumps

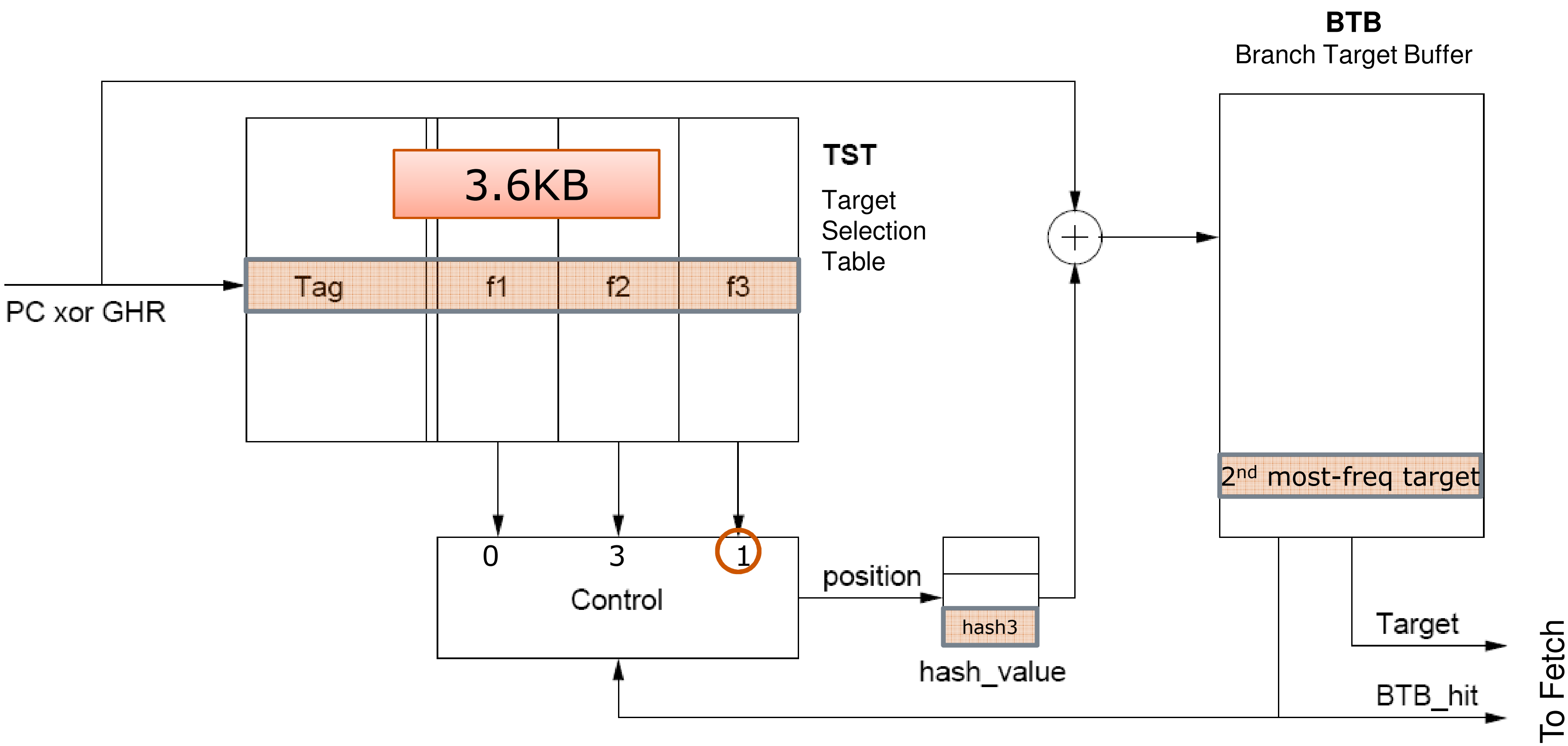
- The compiler uses control-flow analysis and profiling to identify
  - DIP-jumps: highly-mispredicted indirect jumps
  - Control-flow merge (CFM) points
- The microarchitecture decides when and what to predicate dynamically
  - Dynamic target selection

Dynamic Target Selection

- Three frequency counters per entry
- Associated targets in the BTB



Dynamic Target Selection



Additional DIP Entry/Exit Policies

- Single predominant target in the TST
  - TST has more accurate information

    → Override the target prediction

- Nested low confidence DIP-jumps

  → Exit dynamic predication for the earlier jump and re-enter for the later one

- Return instructions inside switch statements
  - Merging address varies with calling site

    → Return CFM points

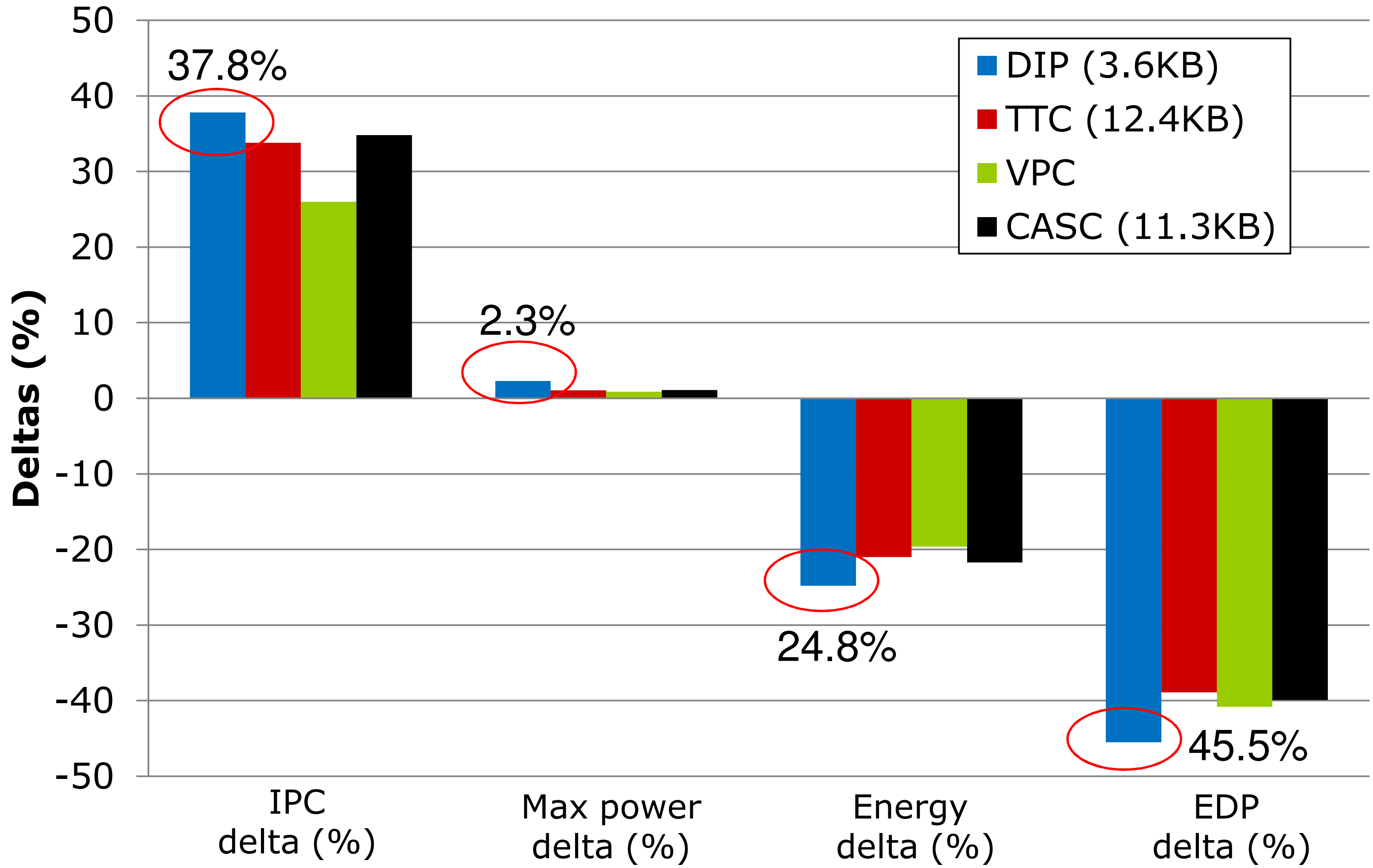
Methodology

- Dynamic profiling tool for DIP-jump and CFM point selection
- Cycle-accurate x86 simulator:
  - Processor configuration
    - 64KB perceptron predictor
    - 4K-entry, 4-way BTB (baseline indirect jump predictor)
    - Minimum 30-cycle branch misprediction penalty
    - 8-wide, 512-entry instruction window
    - 300-cycle minimum memory latency
    - 2KB 12-bit history enhanced JRS confidence estimator
    - 32 predicate registers, 1 CFM register
  - Also less aggressive processor (in paper)
- Benchmarks: DaCapo suite (Java), matlab, m5, perl
  - Also evaluated SPEC CPU 2000 and 2006

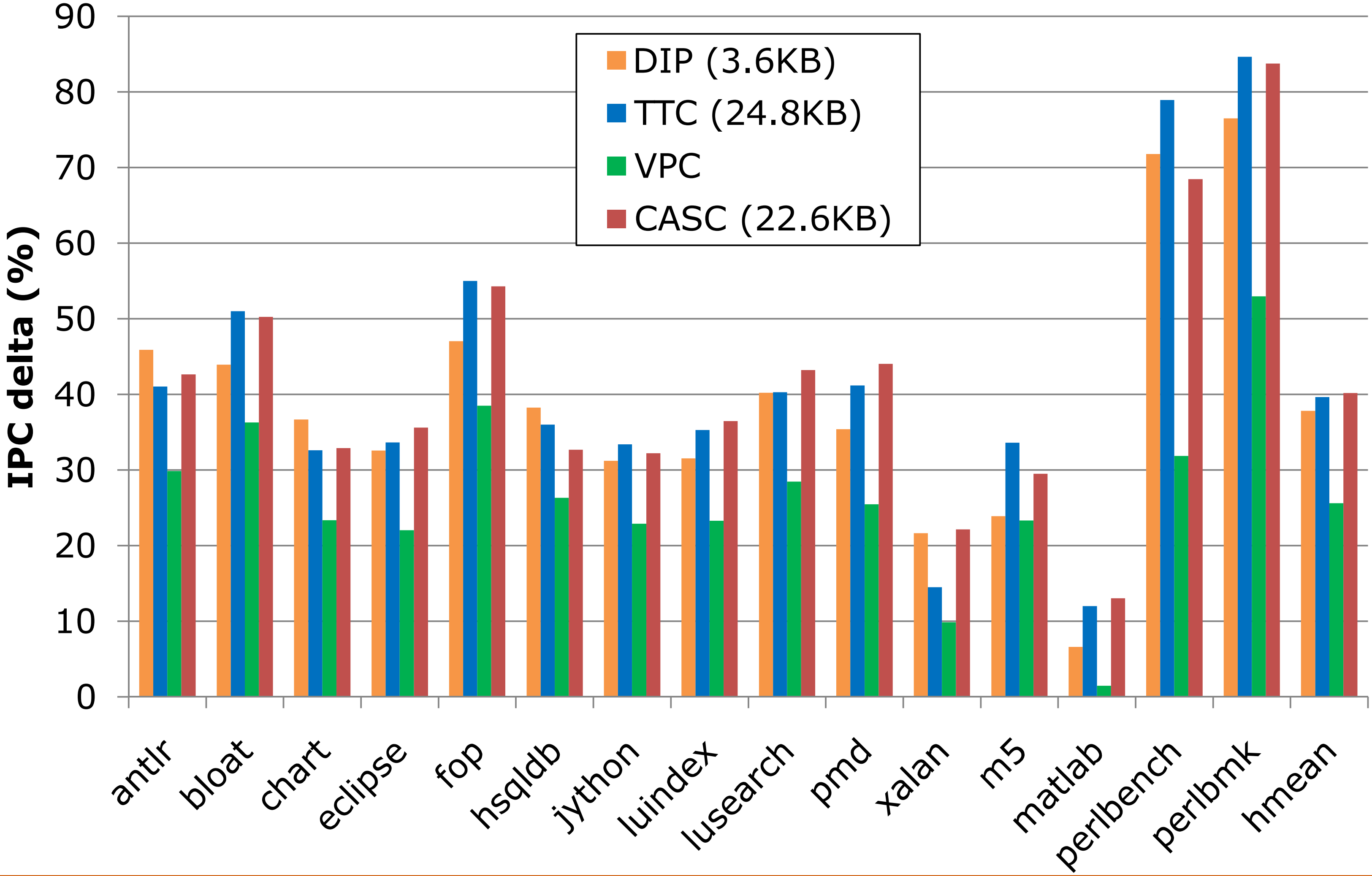
Indirect Jump Predictors

- Tagged Target Cache Predictor (TTC) [P. Chang et al., ISCA 97]
  - 4-way set associative fully-tagged target table
  - Our version does not store easy-to-predict indirect jumps
- Cascaded Predictor [Driesen and Hölzle, MICRO 98, Euro-Par 99]
  - Hybrid predictor with tables of increasing complexity
  - 3-stage predictor performs best
- Virtual Program Counter (VPC) Predictor [Kim et al., ISCA 07]
  - Predicts indirect jumps using the conditional branch predictor
  - Stores multiple targets on the BTB, as our target selection logic does

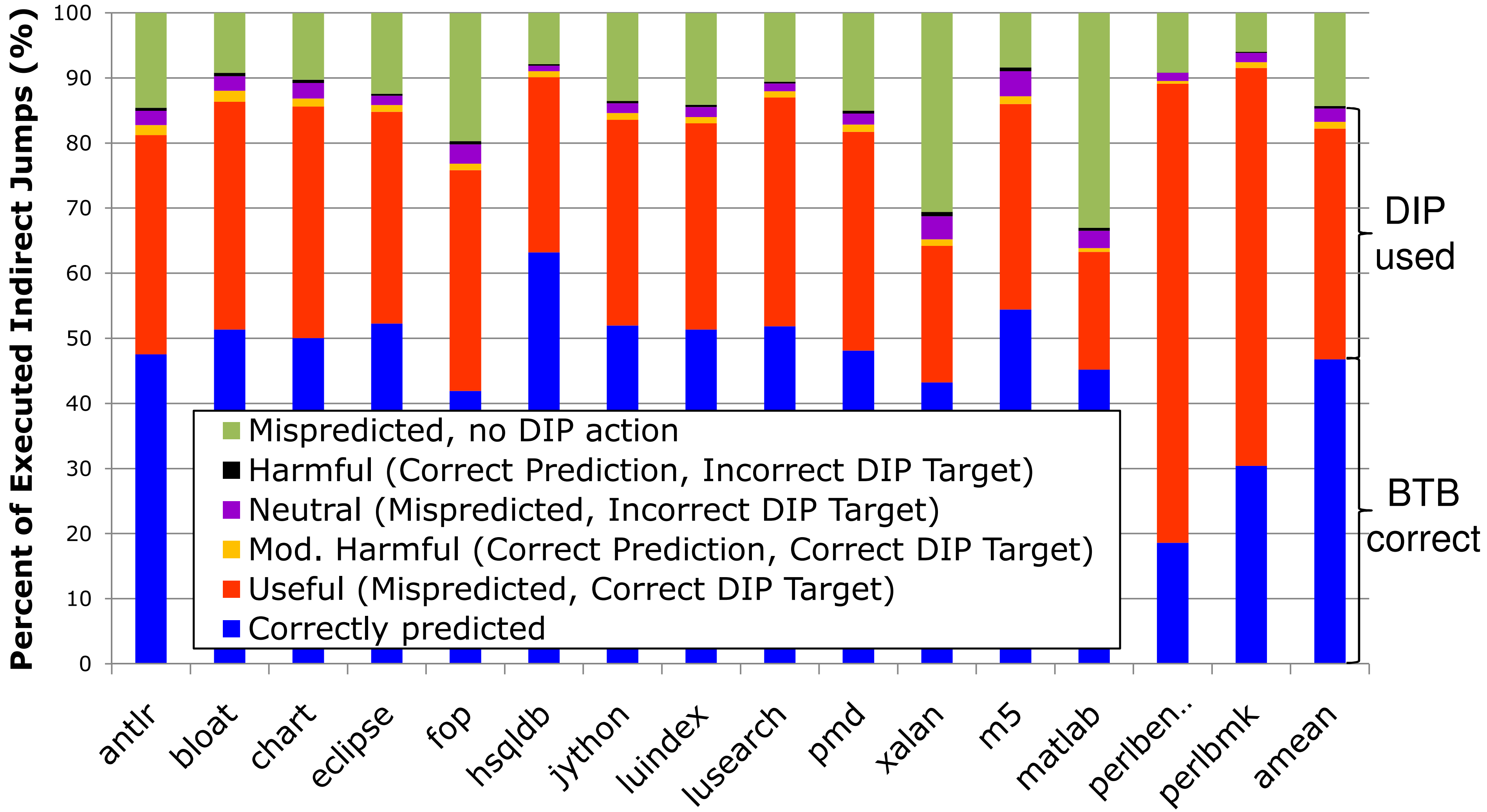
Performance, Power, and Energy



DIP vs. Indirect Jump Predictors



Outcome of Executed Indirect Jumps



Additional Evaluation (in paper)

- Static vs. dynamic target selection policies
- DIP with more than 2 targets → 2 dynamic targets is best
- DIP on top of a baseline with TTC, VPC or Cascaded predictors
- Sensitivity to:
  - Processor configuration
  - BTB size
  - TST size and structure
- More benchmarks (SPEC CPU 2000 and 2006)

Conclusion

- Object-oriented languages use more indirect jumps
  - Indirect jumps are hard to predict and have already become an important performance limiter

- We propose DIP, a cooperative hardware-software technique
  - Improves performance by 37.8%
  - Reduces energy by 24.8%
  - Provides better performance and energy-efficiency than three indirect jump predictors
  - Incurs low hardware cost (3.6KB) if dynamic predication is already used for conditional branches
  - Can be an enabler encouraging developers to use object-oriented programming

Thank You!

Questions?