A Multi-component Branch Predictor Design for Low Resource Budget Processors

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Introduction

- Branch Predictor: an important component of modern processors
  - Predicts branch direction at the fetch stage of the pipeline
  - Saves clock cycles as well as energy for deep pipelines
  - On a misprediction:
    - Pipeline flushed and new instructions brought in
    - Leads to loss of cycles and energy

- Efficient and accurate predictor design – an always important problem in computer architecture community
  - Prediction strategies in modern processors have reached a fair amount of sophistication over decades of research
    - Bimodal, Gshare, Gag, Perceptron, TAGE and its variants
  - Achieving last mile in prediction accuracy is still important
  - With new workloads, new challenges being envisioned

Motivation behind this research

- A single predictor component may not be well suited for all branches in a program
  - Branches ill-suited for a certain branch prediction policy often have better performance when run with another predictor
  - Multicomponent predictor design

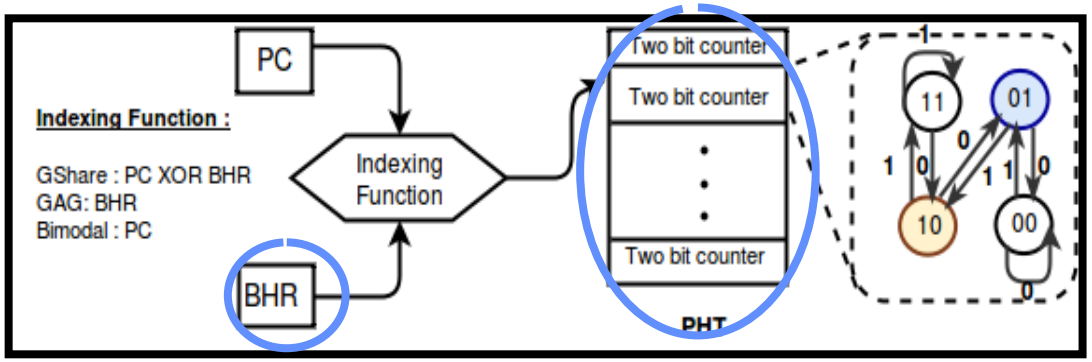
- Multicomponent predictor designs in literature
  - *Best* predictor for each individual branch
  - Separate prediction history storage tables for each predictor
  - Popular Examples: Tournament predictor, Overriding predictor

Contributions of this work

- A new multicomponent predictor design
  - Use of multiple predictor components synergistically instead of a single one for prediction at runtime for better prediction accuracy
  - Does not *necessarily* switch to the best predictor for each branch
- Ensuring a low storage budget design
  - Sharing predictor tables between multiple predictor components
  - A heuristic to minimize inter-predictor interference
- Experimental results on SPEC 2006
  - Accuracy, energy and execution cycle

A multi-component predictor design

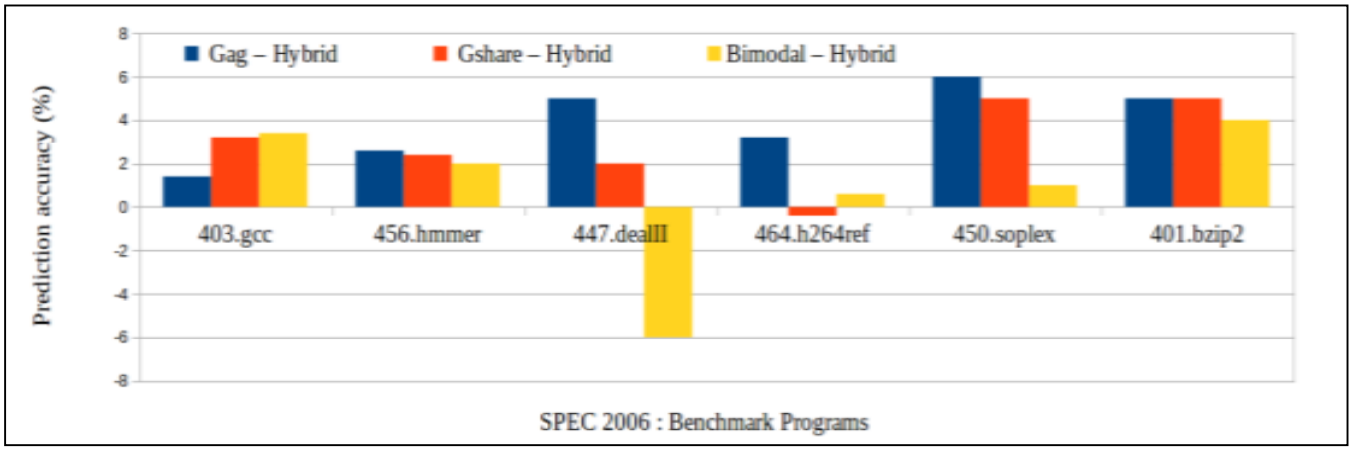
- A combination of 3 components: GShare, Gag and Bimodal predictors
  - Differ in their indexing functions
- Each predictor needs two main storage elements:
  - Branch History Register (BHR)
    - A shift register
    - Stores the branch outcomes of the most recent n branches
    - A 1 is recorded for a *taken* branch, 0 recorded for a *not taken* branch
  - Pattern History Table (PHT)
    - Stores the prediction information for all branches of a program
    - Contains a two bit saturating counter : MSB gives the final prediction



Going for a low storage budget design

- **Classical multi-component predictor design:**
  - Prediction accuracy improvement over single components
  - Individual PHTs for individual predictor components

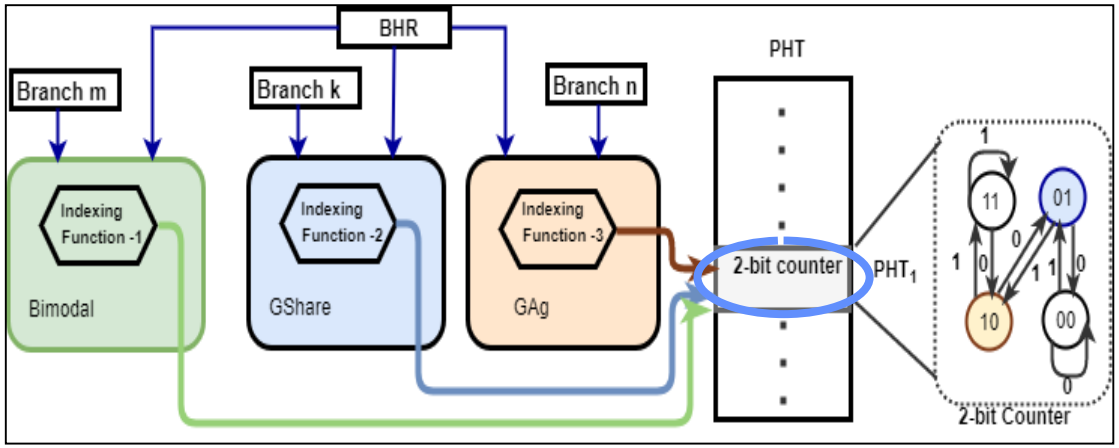
- **Our proposal for low storage budget: a single shared PHT**
  - Leads to prediction accuracy degradation with respect to single components



Accuracy comparison : shared vs individual PHT implementation

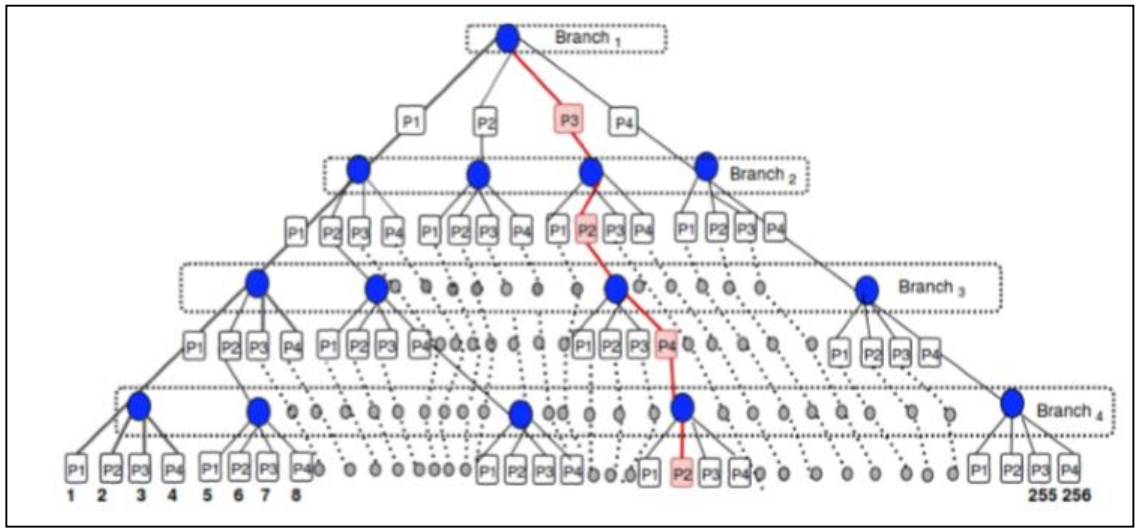
Addressing the accuracy degradation

- Inter predictor interference
  - Information stored by one predictor accessed and modified by others
  - Increase in Misprediction
- Too many instances of predictor switching
  - Switching between predictors to employ the best predictor for each branch does not necessarily help
- Question: Can we find a predictor usage sequence that minimizes mispredictions, and therefore, maximizes accuracy?



Complexity of the solution space

- Simulate all sequences of possible combinations of all branches for all predictors
- Example: 4 predictors and 4 branches
  - 256 combinations
  - Infeasible for program with more branches



Predictor Sequence Tree

Our multi-component predictor strategy

- Attempts to reduce the instances of inter-predictor interference
- Does not necessarily switch predictors at each branch
  - For each branch, evaluates the benefit of changing the predictor from the one currently being used
  - Changes the current predictor only if accuracy improvement is significant

```
Algorithm /* A_q denotes the prediction accuracy of predictor q */
R = predictor with maximum average prediction accuracy for a program
Initialize currentPredictor C = R
For each branch i  in the program do
      Let P_i be the best predictor if available, or else P_i =R
      if |A_c-A_Pi | < Θ then
            select C for prediction of i
      else
            select P_i for prediction of i
            update C = P_i
End Algorithm
```

Discussion on our proposal

- Can still manage with a single PHT shared between the components
- Accuracy degradation is not as significant as in the naive shared design
- Controls interference using lesser number of predictors
  - Total number of interfering predictors is usually less than the classical scheme
  - The worst case number of predictor switches in our case is upper bounded by the number of switches in a classical scheme

Experimental setup

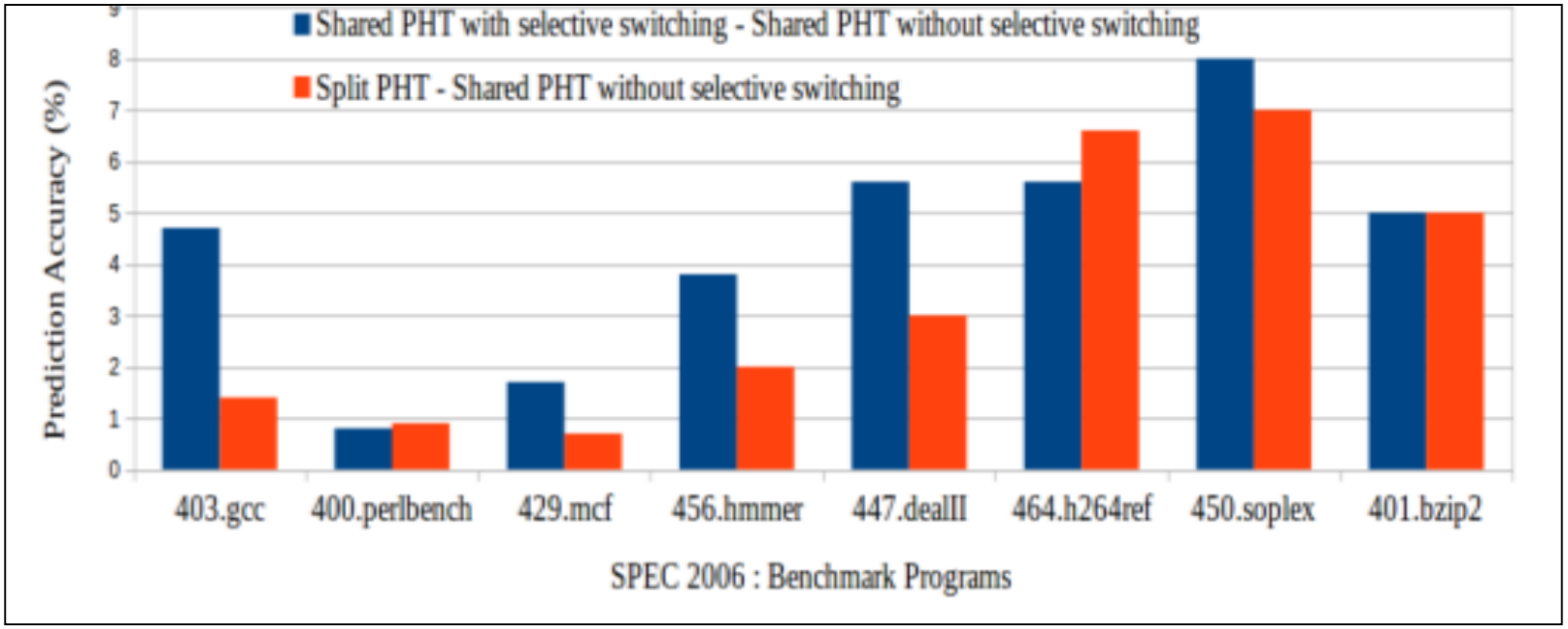
- Tejas architectural simulator
- SPEC 2006 benchmark programs
- Shared PHT implementation
  - 32 KB PHT size – shared by three predictors
- Compared the performance benefits of our design with
  - A naïve shared PHT implementation (without our heuristic)
  - Split PHT implementation, with16 KB PHT for each predictor

Comparing the number of interferences

Benchmark	Interference (in shared implementation) (%)	Interference (using switching algorithm) (%)
403.gcc	3.7	2.2
400.perlbench	4	3.3
429.mcf	1.2	0.5
458.sjeng	1	0.2
456.hmmr	1.1	0.05
447.dealII	1	0.1
464.h264ref	2	0.7
450.soplex	2.5	1.2
401.bzip2	3.4	0.4

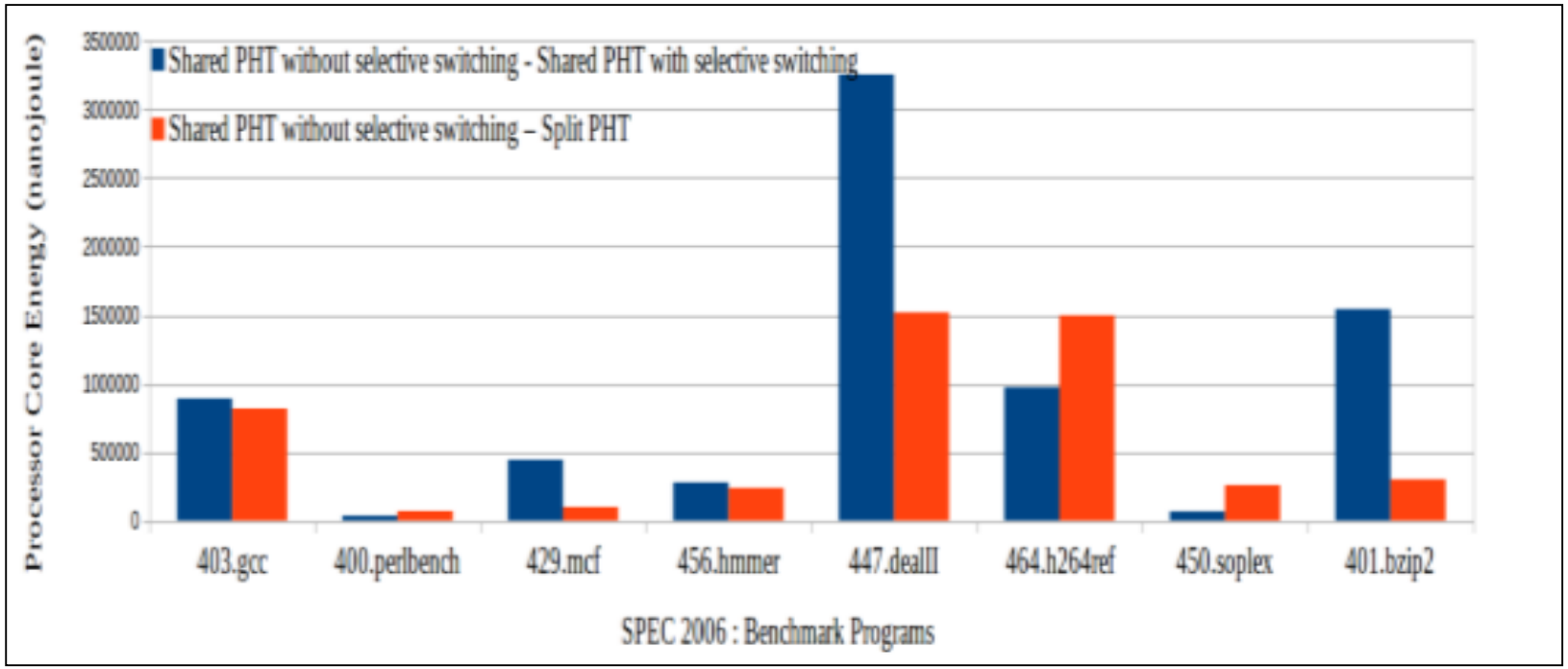
- % of interferences in the naive shared implementation versus ours
- Achieved reduction in all cases

Prediction Accuracy Comparison



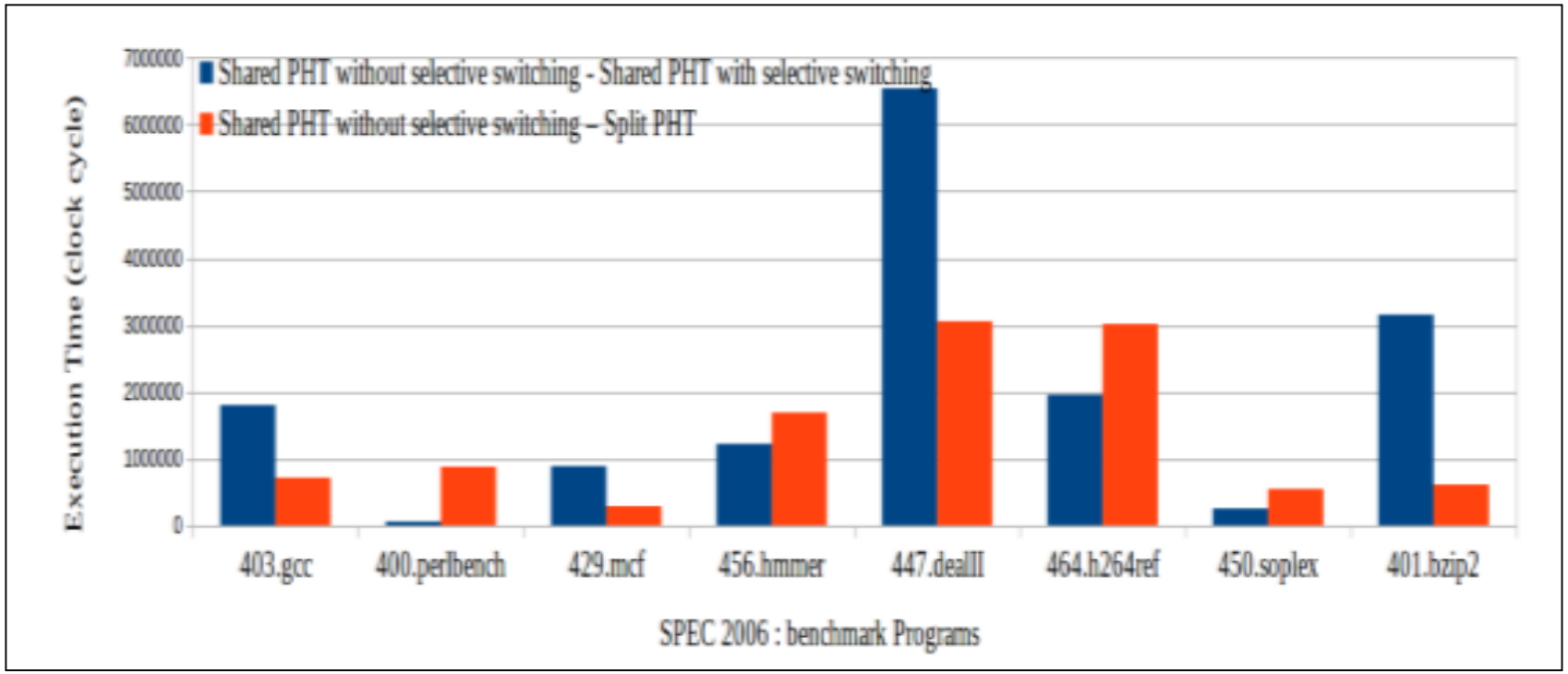
- Average accuracy improvement - around 2%-3%

Energy Comparison



- Improvement in execution time over a naive shared PHT implementation
- Improvement recorded over a SPLIT table implementation

Execution Time Comparison



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- Improvement recorded over a SPLIT table implementation

Comments on our approach

- Leads to improvement in accuracy, energy and execution time
- Utilizes a static profile based selection scheme to identify and record the best predictor for each branch
  - Need to store this information for use at execution time
  - Decision to switch done at execution time
- Attempts to minimize negative interference
  - Benefits of positive interference lost as well
- Can implement this at run-time, switching at phases
  - Can keep track of best predictor information as execution progresses

Thank You !