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Detecting Global Stride Locality in Value Streams

Huiyang Zhou, Jill Flanagan, Thomas M. Conte

TINKER Research Group
Department of Electrical & Computer Engineering
North Carolina State University

Introduction

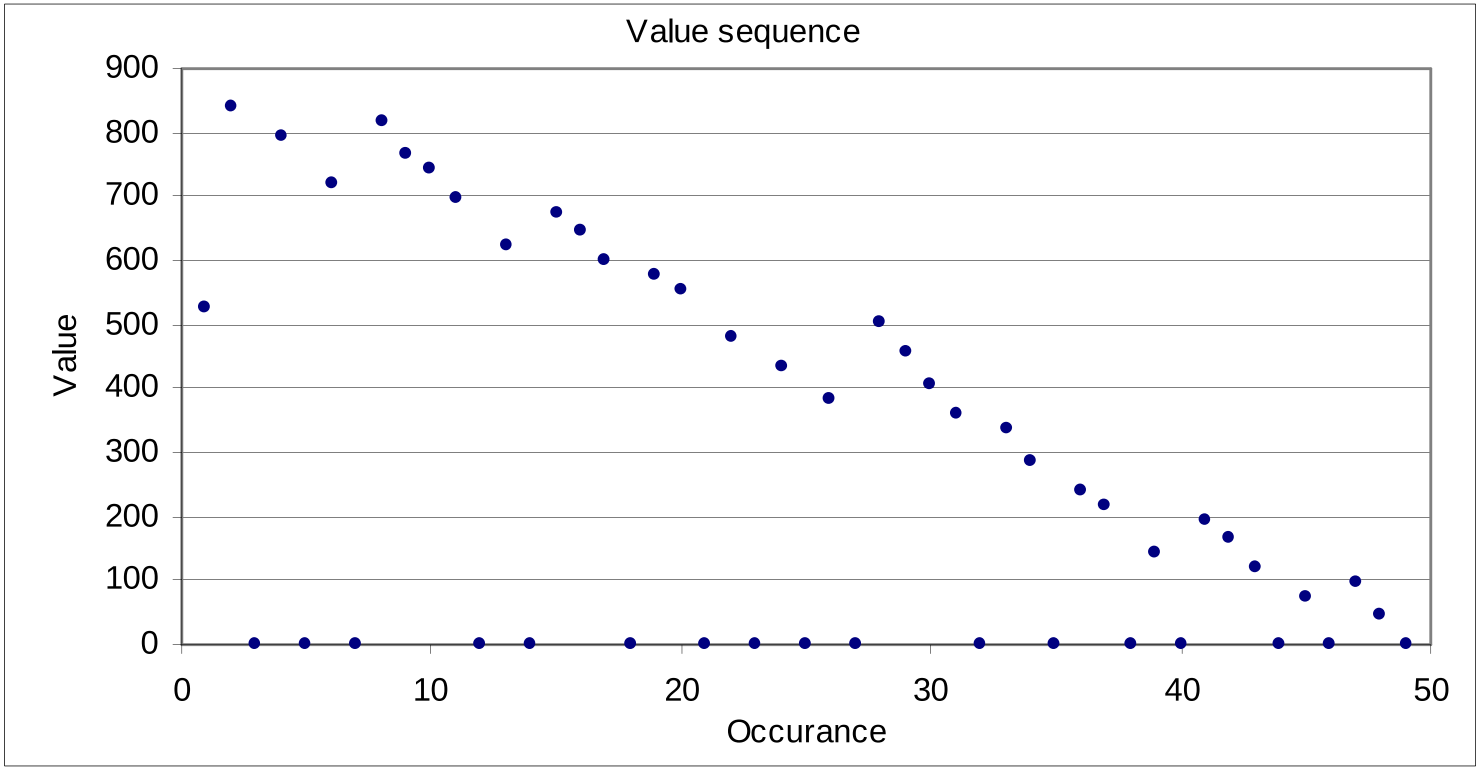
- This paper is about predicting values …

- A code example (from the benchmark ***parser***, function ***is_CON_word***)

```
....
00400740  lw $v0[2],0($v1[3])
00400748  sw $v0[2],0($s8[30])
00400750  lw $v0[2],0($s8[30])      //the insn to be predicted
00400758  bne $v0[2],$zero[0],00400768
....
....
00400798  lw $v0[2],0($s8[30])
004007a0  lw $v1[3],12($v0[2])
004007a8  sw $v1[3],0($s8[30])
004007b0  j 00400750
....
```

local value history from value profile: xx528, xx840, 0, xx792, 0, xx720, 0, xx816, xx768, xx744, xx696, xx624, xx672, …

Hard-to-Predict Values



Hard to predict with (local) value predictors:

DFCM [Goeman et.al.]: 2% accuracy;

(local) stride [Lipasti et. al.]: 4% accuracy.

Global Value Locality

- Another look at the code

```
....
00400740  lw $v0[2],0($v1[3])    //the correlated load
00400748  sw $v0[2],0($s8[30])
00400750  lw $v0[2],0($s8[30])  //the instruction to be predicted
00400758  bne $v0[2],$zero[0],00400768
....
....
00400798  lw $v0[2],0($s8[30])
004007a0  lw $v1[3],12($v0[2])  //the correlated load
004007a8  sw $v1[3],0($s8[30])
004007b0  j 00400750
....
```

Global Stride Locality

Control flow graph

```
…
00400740  lw $v0[2],0($v1[3])
          // the correlated load
00400748  sw $v0[2],0($s8[30])
```

```
…
004007a0  lw $v1[3],12($v0[2])
          //the correlated load
004007a8  sw $v1[3],0($s8[30])
004007b0  j 00400750
```

```
00400750  lw $v0[2],0($s8[30])
          //the instruction to be predicted
00400758  bne $v0[2],$zero[0],00400768
```

100% prediction accuracy is possible if we can use the results of correlated instructions.

Global Value History

- Global value history:
  - If the values produced by the dynamic instruction stream are labeled x_1, x_2, ..., x_N, then the ordered data sequence (x_1, x_2, ..., x_N) is the global value history of order (i.e., length) N.
- Local value history
  - The value sequence produced by the same instruction to be predicted.

Global Value Locality

- Similar to local value predictability [Sazeides and Smith]

- Global context locality
  - Previous instruction (PI) predictor [Nakra et.al.]
  - Dynamic dataflow-inherited speculative context (DDISC) predictor [Thomas & Franklin]

- Global computational locality

$$x_N = a_{N-1}x_{N-1} + a_{N-2}x_{N-2} + \ldots + a_1x_1 + a_0.$$

Similar formulation to "Perceptron branch predictor" [Jimenez & Lin]

Global Stride Locality

- Global stride locality

$$x_N = x_{N-k} + a_0.$$

k and a_0 are run-time variables

- The previous example: $x_N = x_{N-1}$

```
…
00400740  lw $v0[2],0($v1[3])
          // the correlated load
00400748  sw $v0[2],0($s8[30])
```

```
…
004007a0  lw $v1[3],12($v0[2])
          //the correlated load
004007a8  sw $v1[3],0($s8[30])
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```

```
00400750  lw $v0[2],0($s8[30])
          //the instruction to be predicted
00400758  bne $v0[2],$zero[0],00400768
```

Global Stride Locality In A Program

- Global stride locality in the code

```
…
Define (e.g., load ra, rb, rc)    // load value is hard to predict
…
Explicit Use (e.g., add rx, ra, #constant) // the dest of add can be
        //predicted using the value of the define instruction results (ra)
…
Explicit Use (e.g., sub rx, ra, rd)   //  the dest of sub can be predicted
        //if rd has strong repeating patterns
…
Implicit Use (e.g., load rx, ry, rz)    //Implicit use through the
        //memory (eg., spilling and filling; reloading)
```

Global Stride Locality In A Program (cont.)

- Global stride locality embedded in the data structure

```
struct  string_list {
struct  string_list * next;
char * string;
}
```

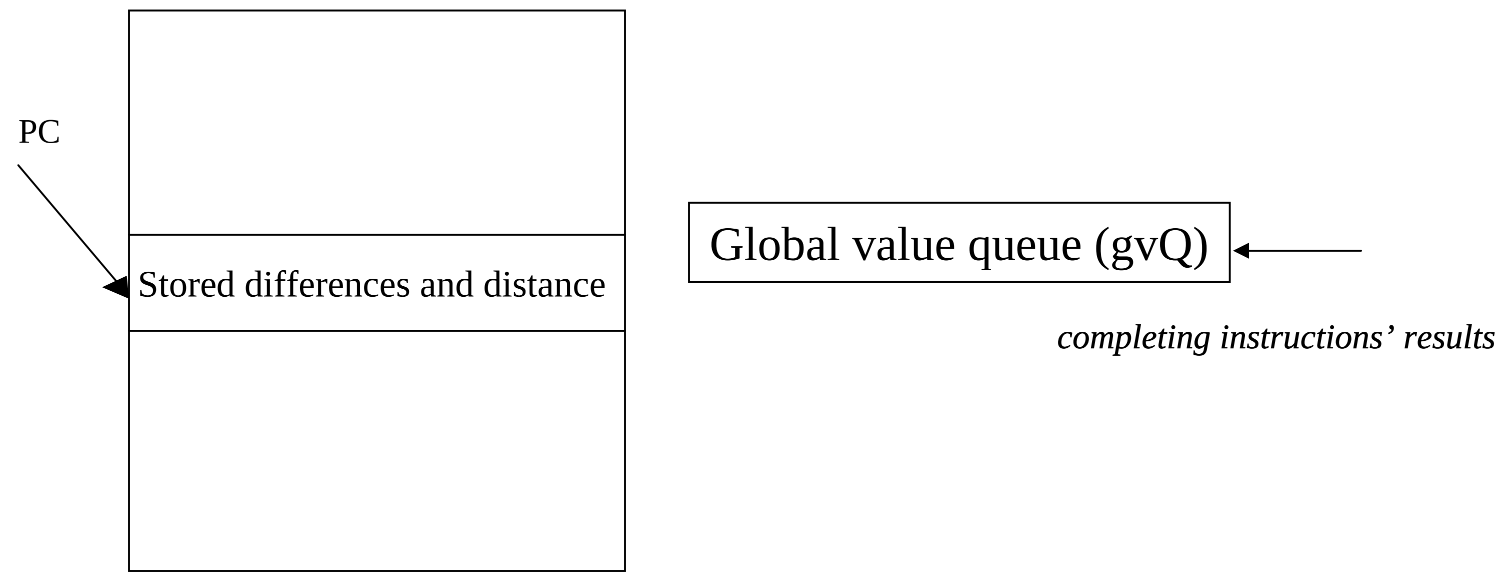
Near constant stride between the two addresses (**next*, **string*) if the two fields (*next*, *string*) are allocated and referenced in the same order. [Serrano & Wu]

Outline

- Introduction of global stride locality
- GDiff predictor
- Value Delay
- Speculative Value Queue
- Hybrid Value Queue
- Potential uses of gDiff predictor
- Summary

The GDiff Value Predictor

Two major structures



Prediction table

Example

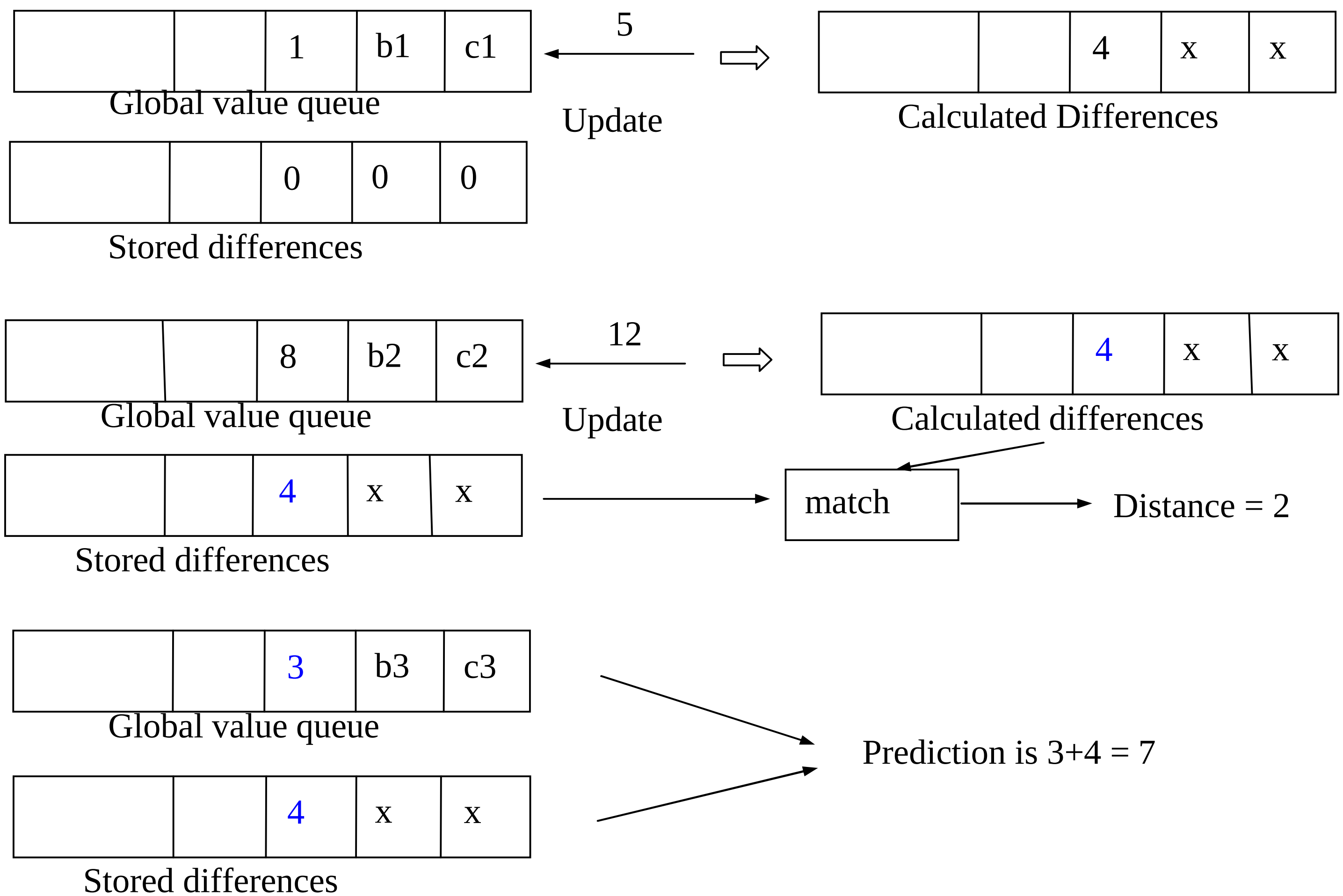
- A code example

```
…
a:  load r1, r2, #20
b:
c:
d:  add r3, r1, #4
…
```

(loop: d → a)

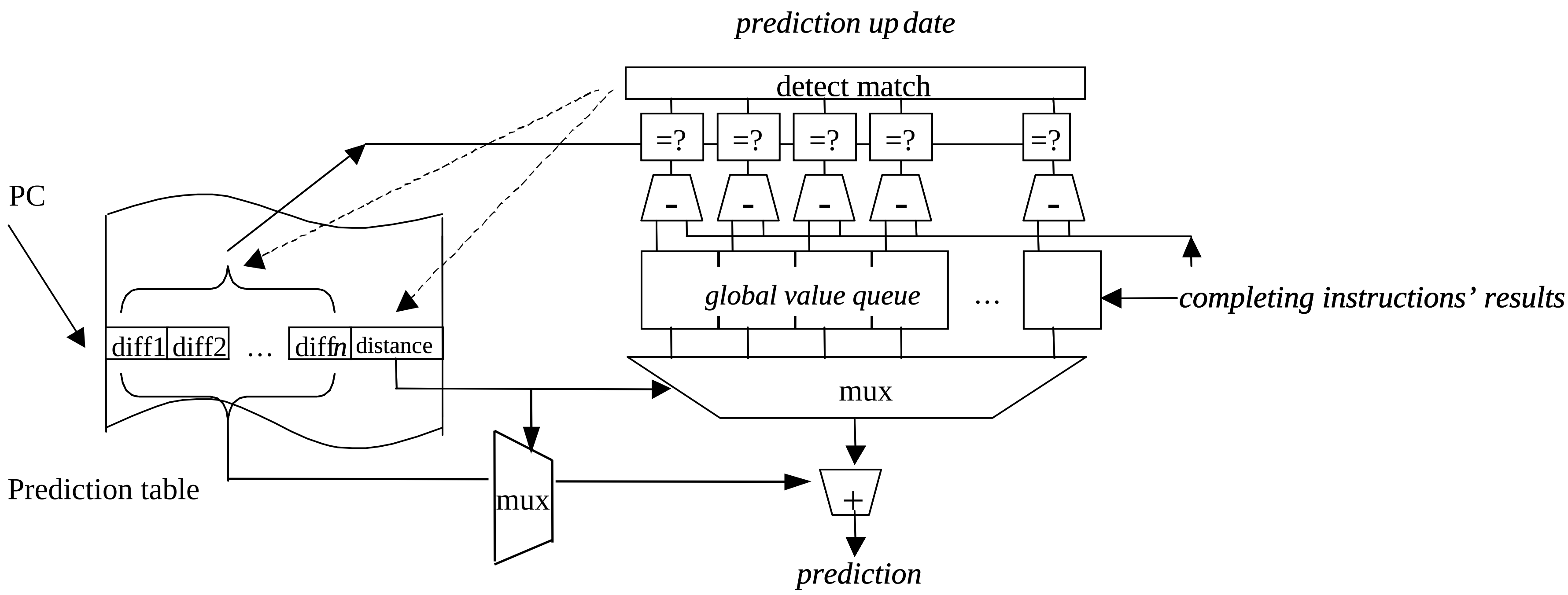
Instruction *a* produces (1, 8, 3, 2, …)
Instruction *d* generates (5, 12, 7, 6, …)

How GDiff Works



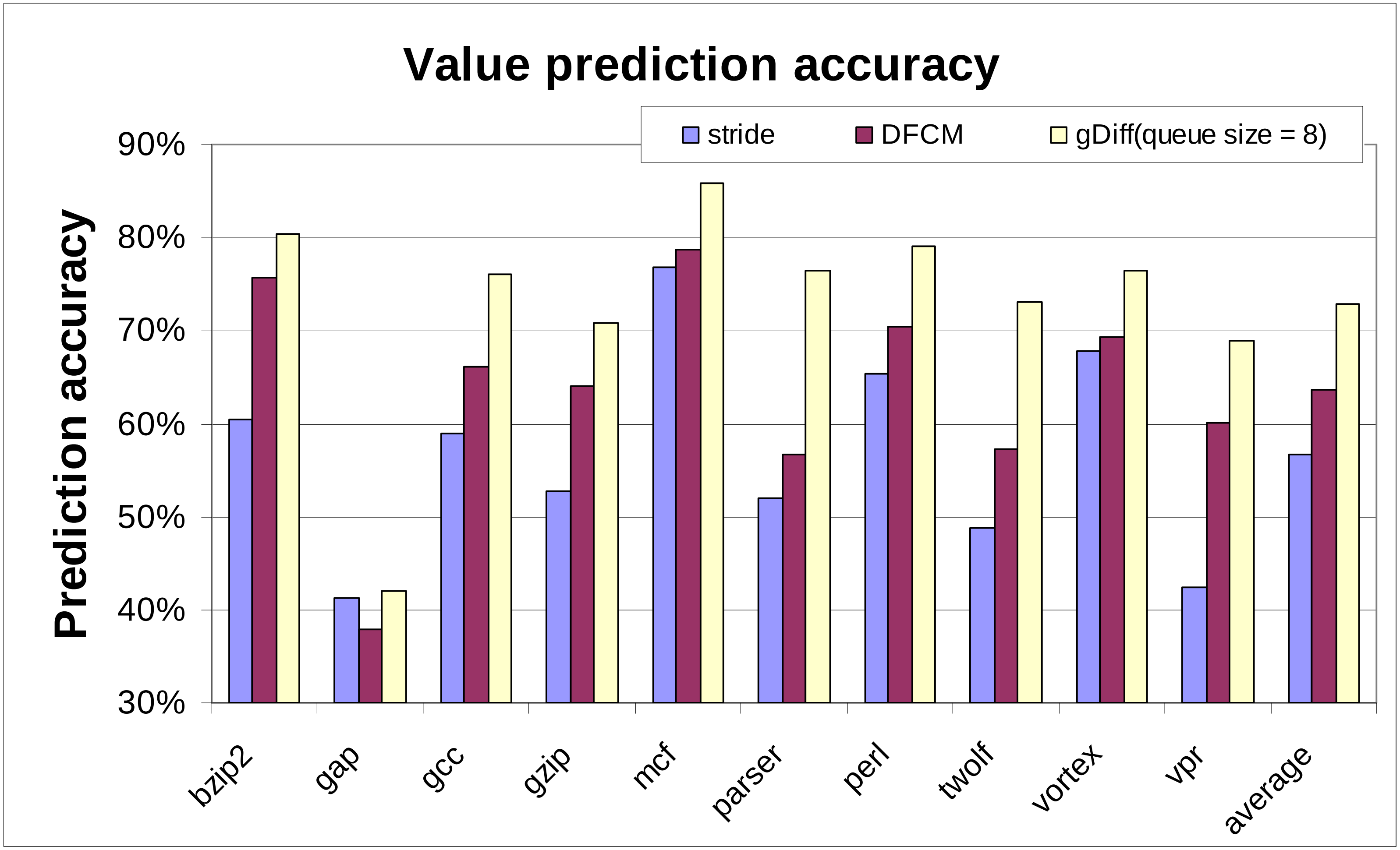
Instruction *a* produces (1, 8, 3, 2, …)
Instruction *d* generates (5, 12, 7, 6, …)

The GDiff Value Predictor



$$x_N = x_{N-k} + a_0.$$

Results: Exploiting Global Stride Value Locality



Based on trace simulation (sim-profile) and predicting all value producing insns

Stride, gDiff, DFCM L1: 8k entry pc-indexed tagless table; DFCM L2: 64K entry table

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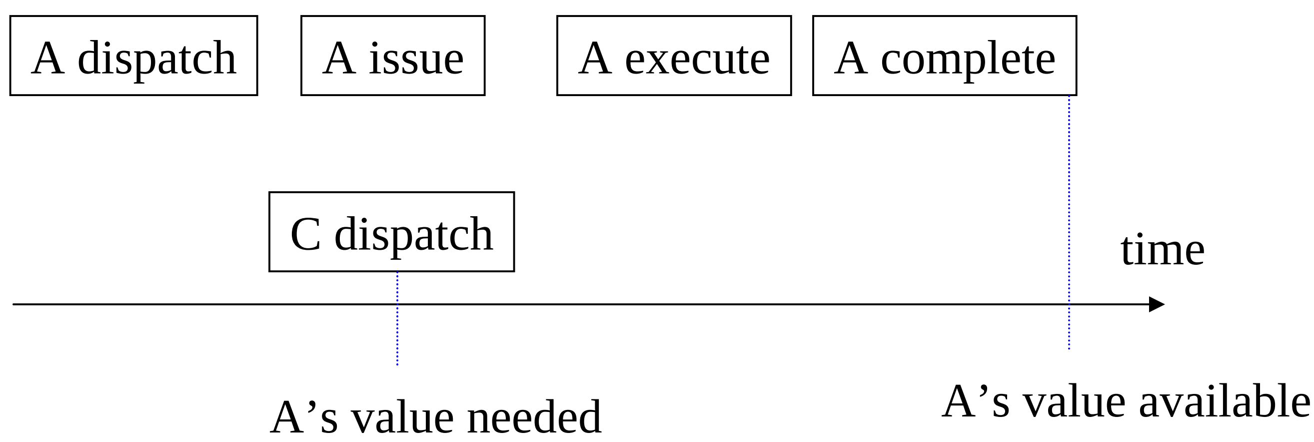
Value Delay

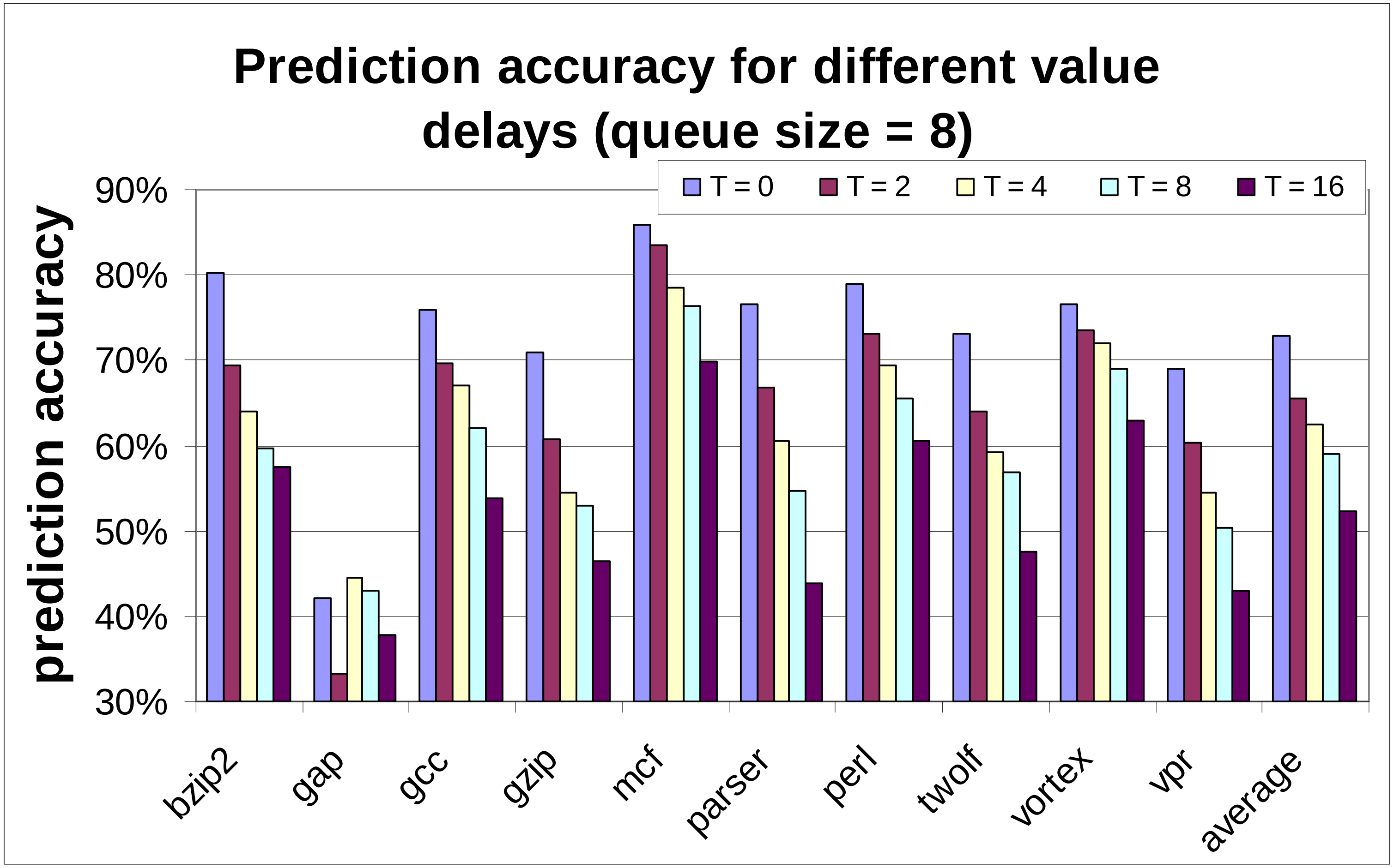
- When the prediction of an instruction is being made, the correlated instruction has not finished

```
....
A. lw $v0[2],0($v1[3])            //the correlated load
B. sw $v0[2],0($s8[30])
C. lw $v0[2],0($s8[30])           //the instruction to be predicted
D. bne $v0[2],$zero[0],00400768
....
```



Value Delay Impact

Model value delay as T values: a prediction can not use the previous T insns' results.



Trace simulation using sim-profile

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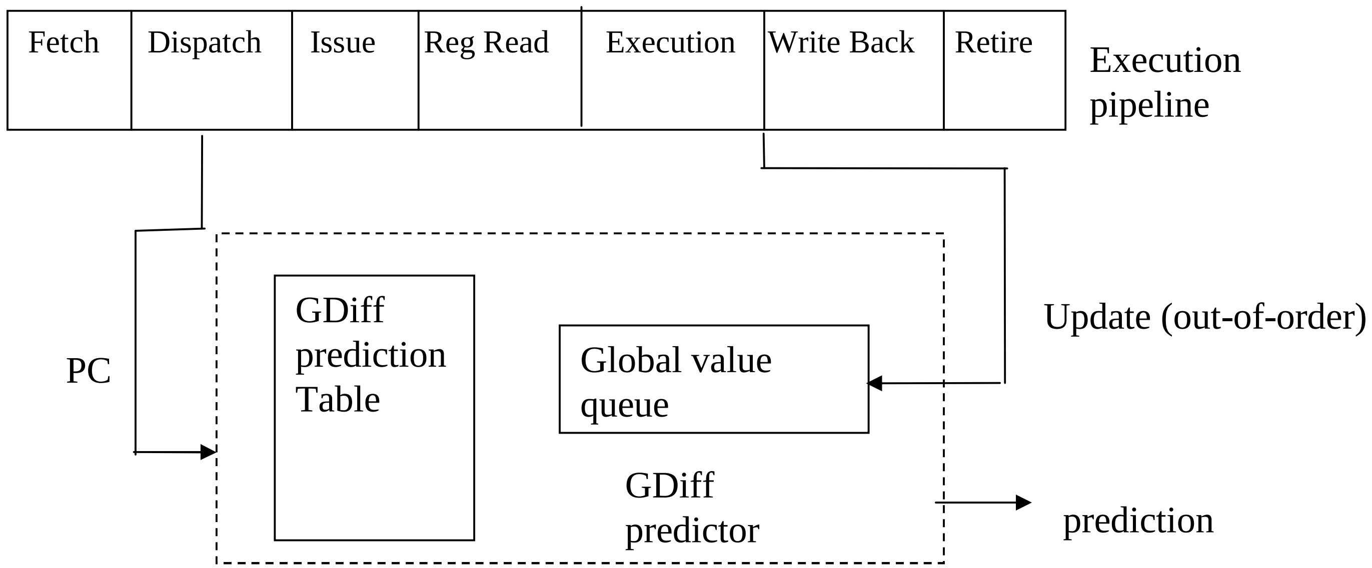
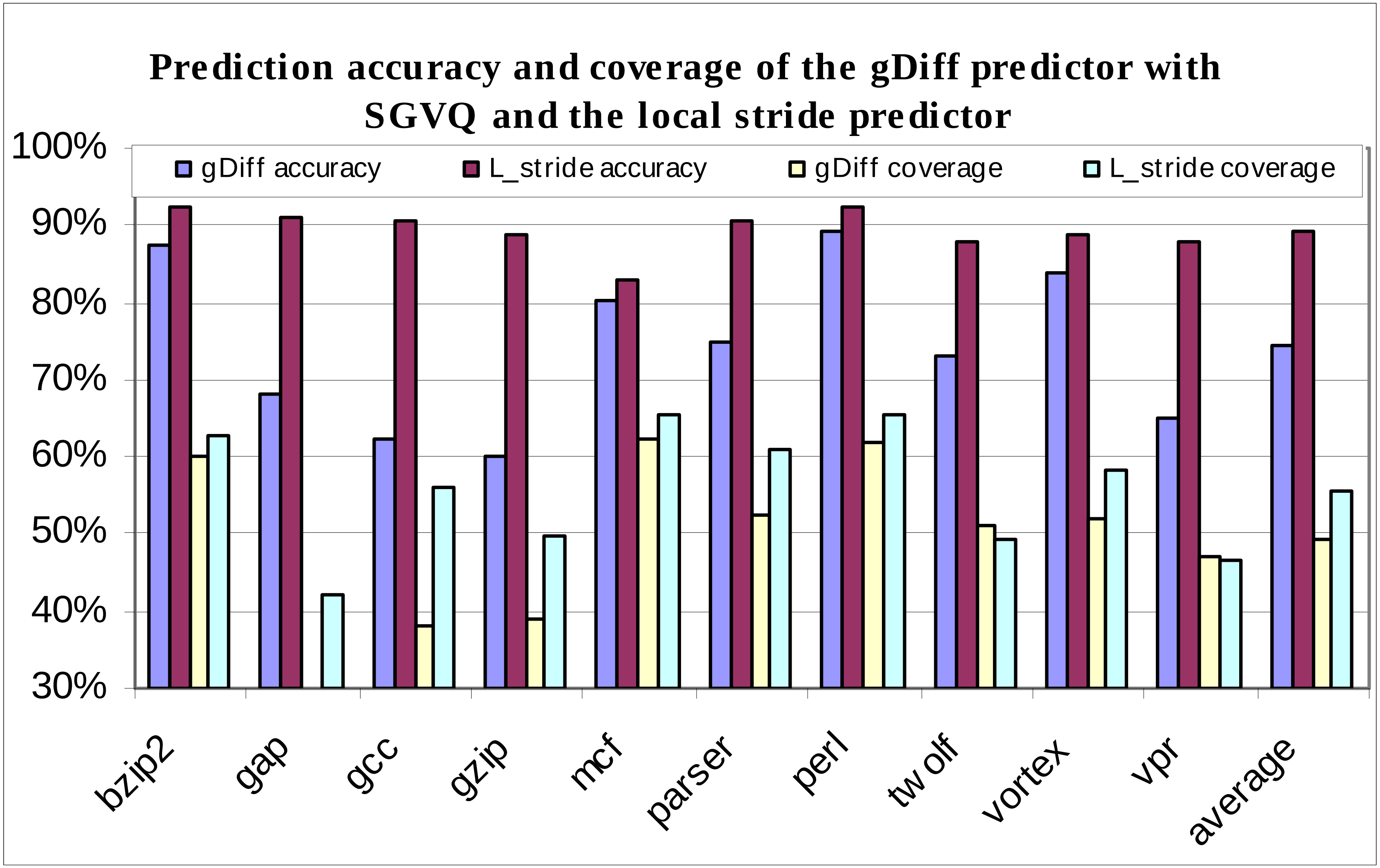
Reducing the Value Delay



Gdiff with speculative value queue (SGVQ)

Results of SGVQ



Worse than the simple local stride predictor. Why?

Problems with Speculative GDiff

- Though value delay is reduced.
- The results are out-of-order

Completion order

…
a: add r3, r4, r5
…
b: load r5, r6, 28
…
c: sub r2, r3, 4
…

Cache miss

…
b: load r5, r6, 28
…
a: add r3, r4, r5
…
c: sub r2, r3, 4
…

Cache hit

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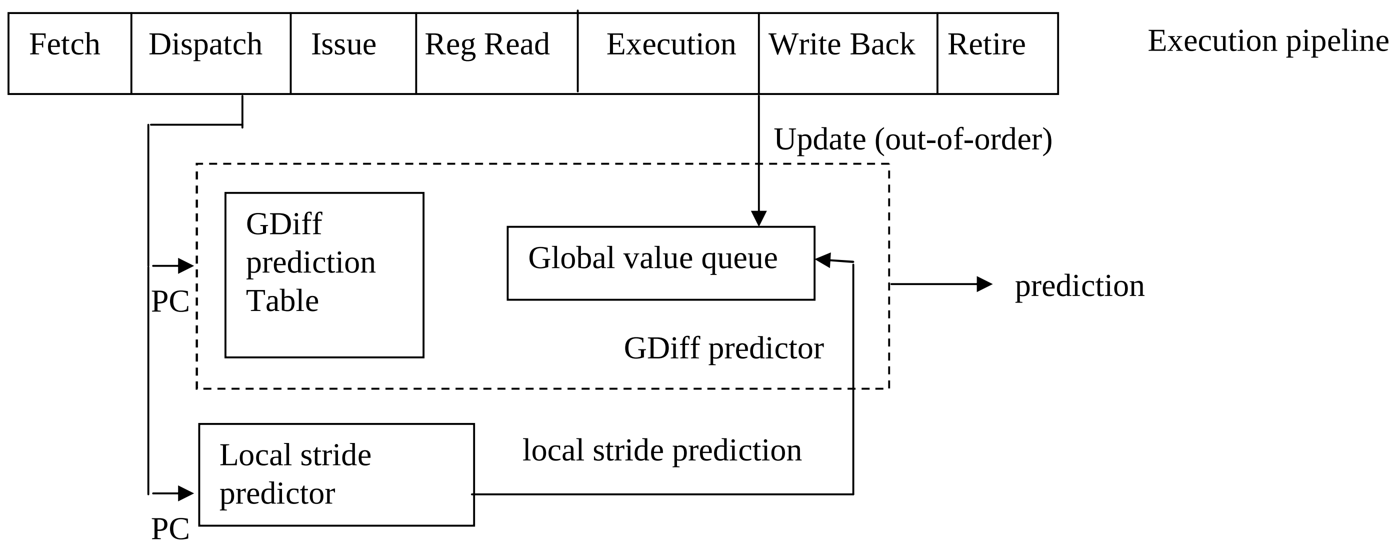
The Hybrid GDiff Value Predictor



Key: construct the global value history *in-order (fetch/dispatch order)*; combine with a different value predictor.

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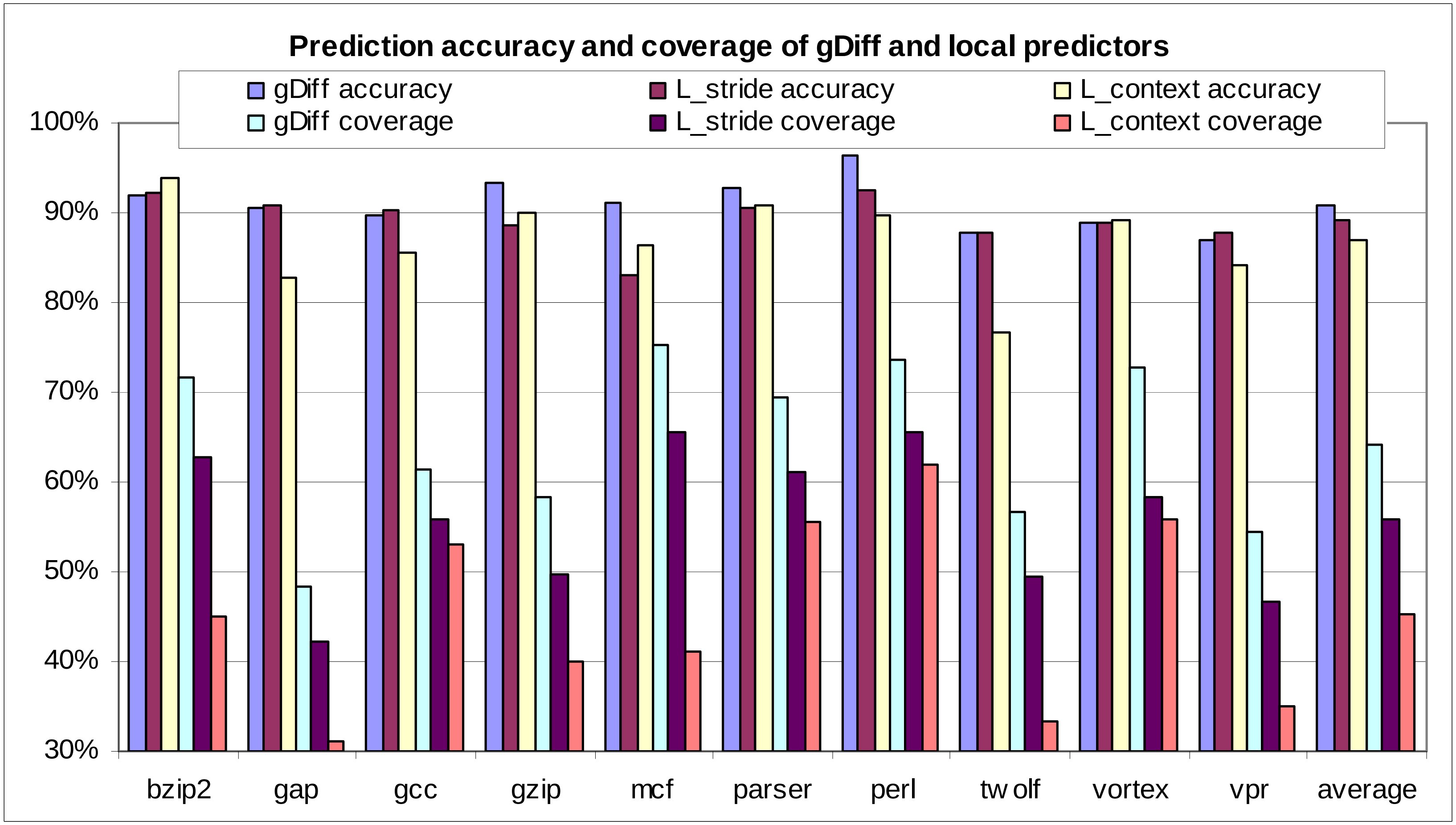
Results of Hybrid GDiff

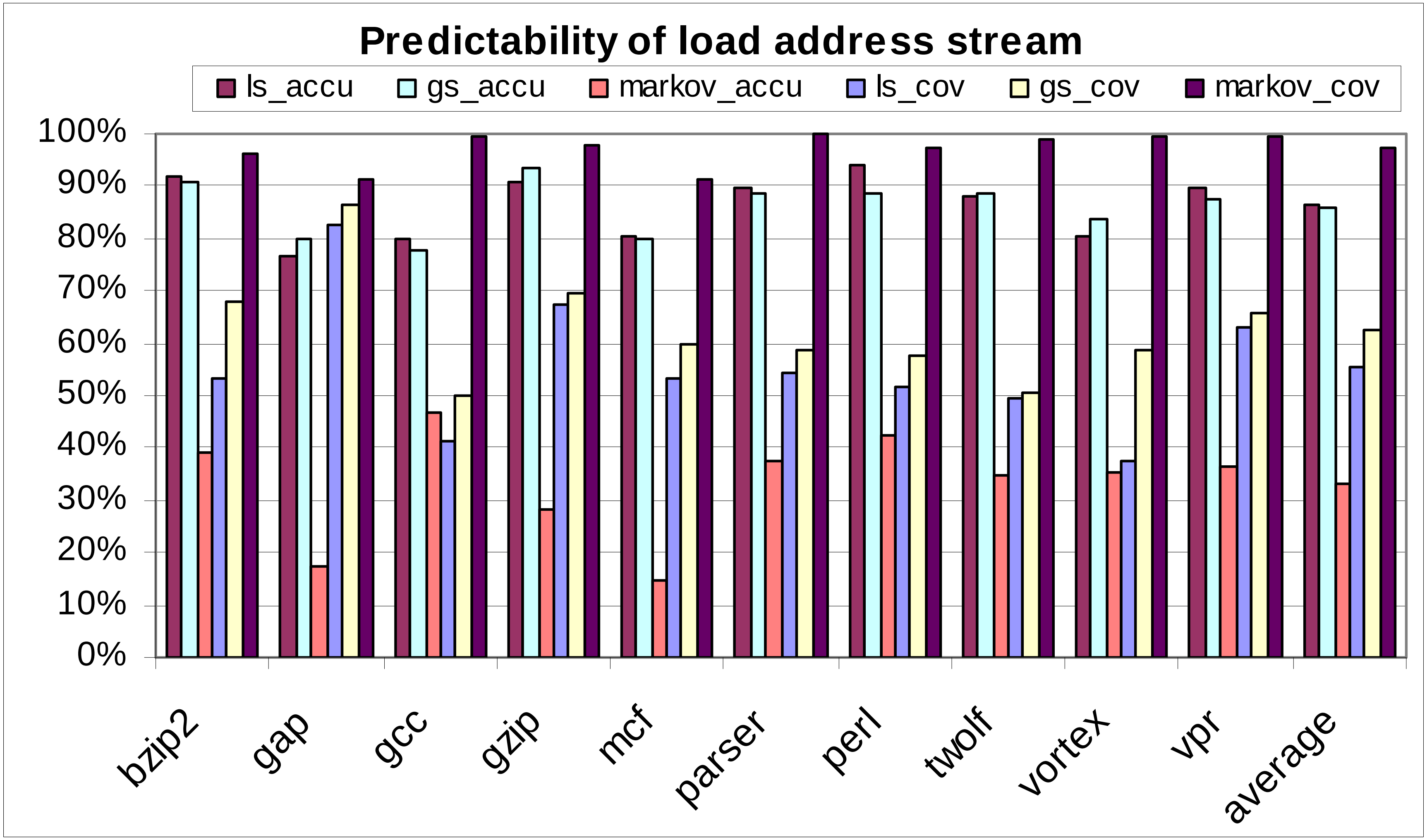


(Local context uses DFCM)

Potential Uses of GDiff

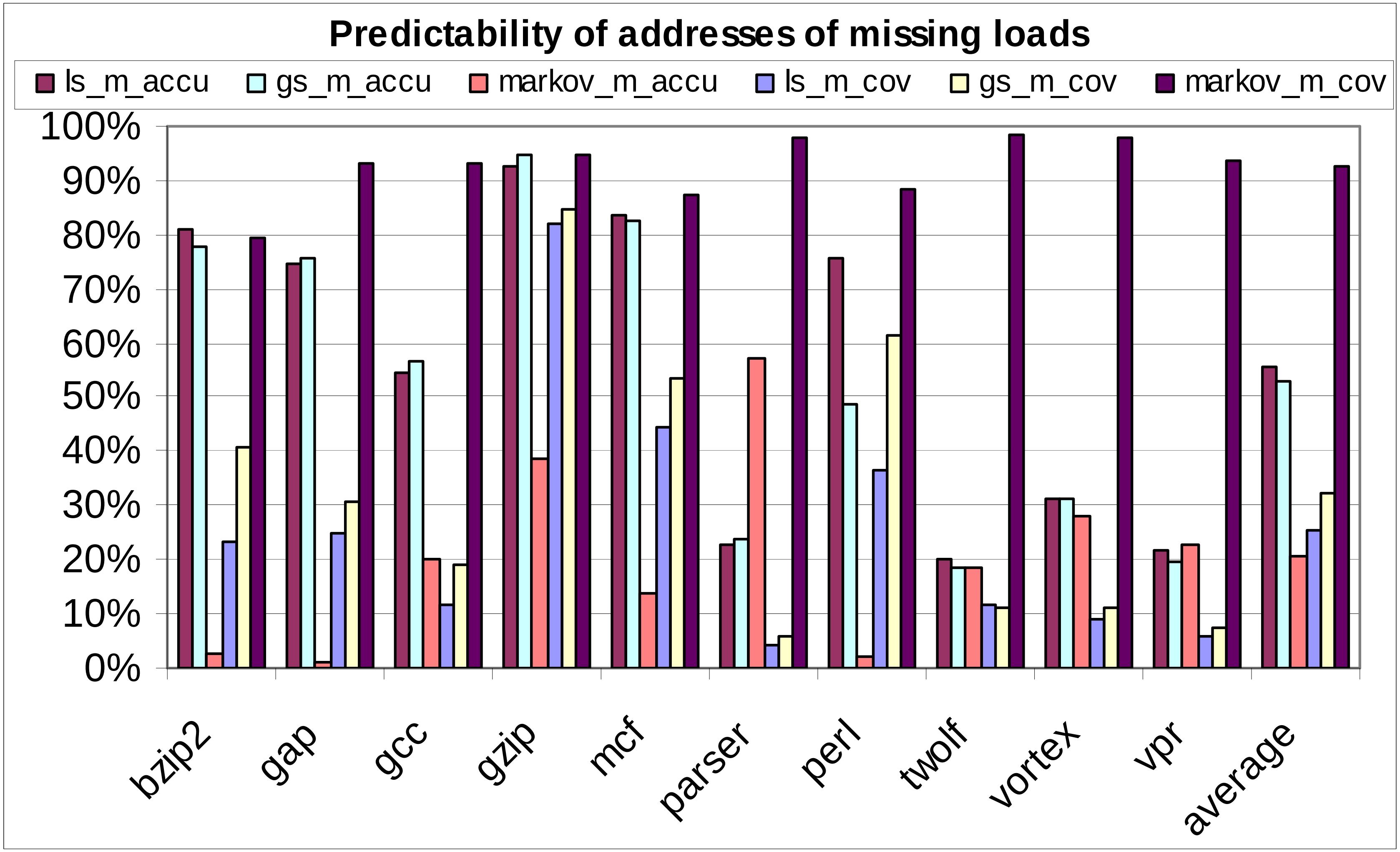
- Predicting load addresses.
  - Forming the global value history only with load addresses.
  - Predict next address based on previous addresses.
- Predicting addresses of missing loads only
  - Forming the global value history only with addresses of missing loads.
  - Predict next address based on previous addresses.
- Predicting values to break true data dependence chain.
- And …

Predicting Addresses Using Hybrid GDiff

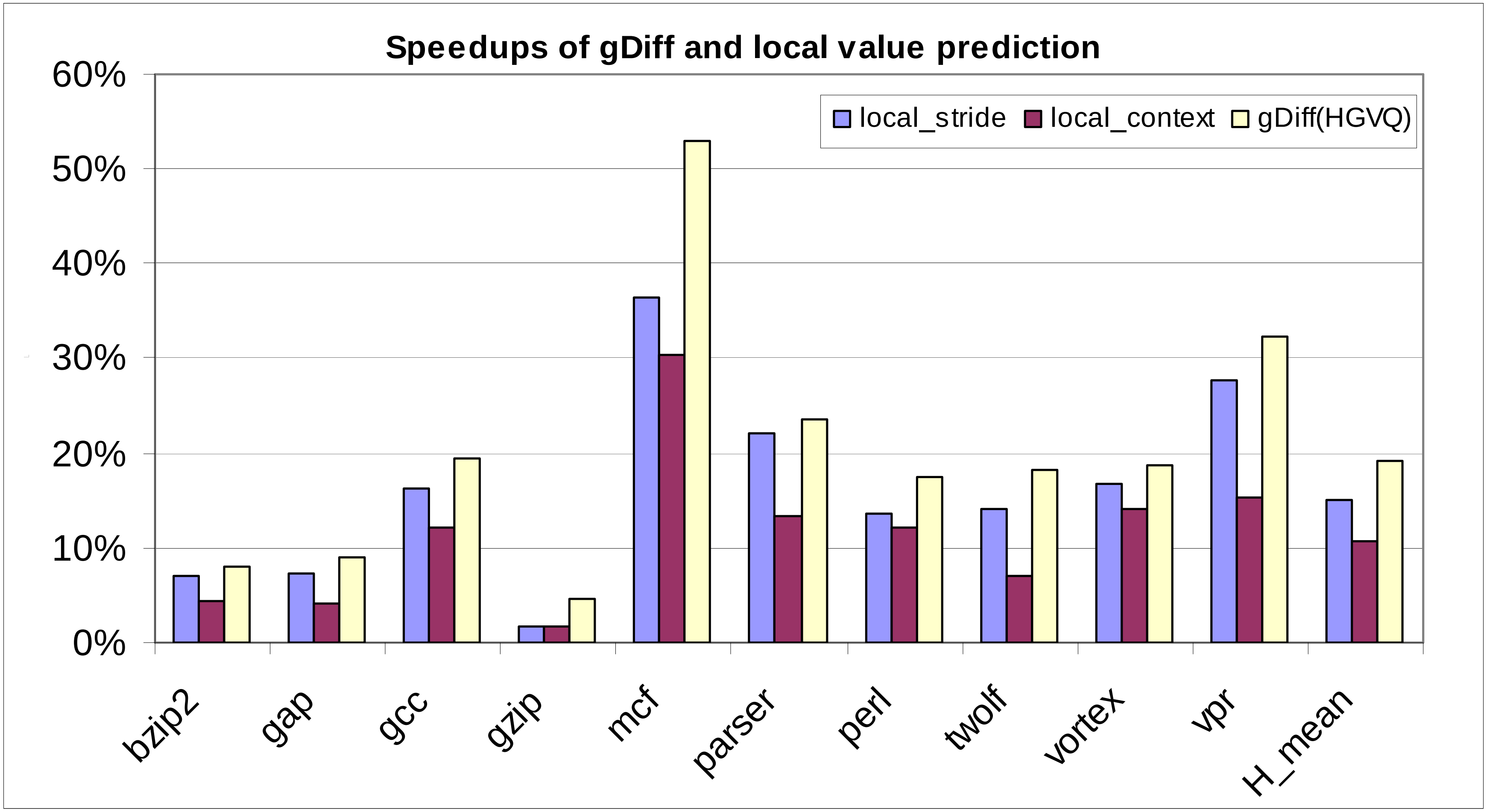


4-way 256k entry Markov address predictor uses tag for confidence

Predicting Address of Missing Loads



Using GDiff to Break Data Dependencies



4/64 issue out-of-order model

Summary

- Global stride locality
- The Gdiff value predictor
- Value delay issue
- Reduce the value delay
- In-order global value history
- Potential Uses:
  - What to put into the global value queue (i.e., global value history)
  - How to utilize the prediction

Thank you and Questions?