Execution Slack and Criticality

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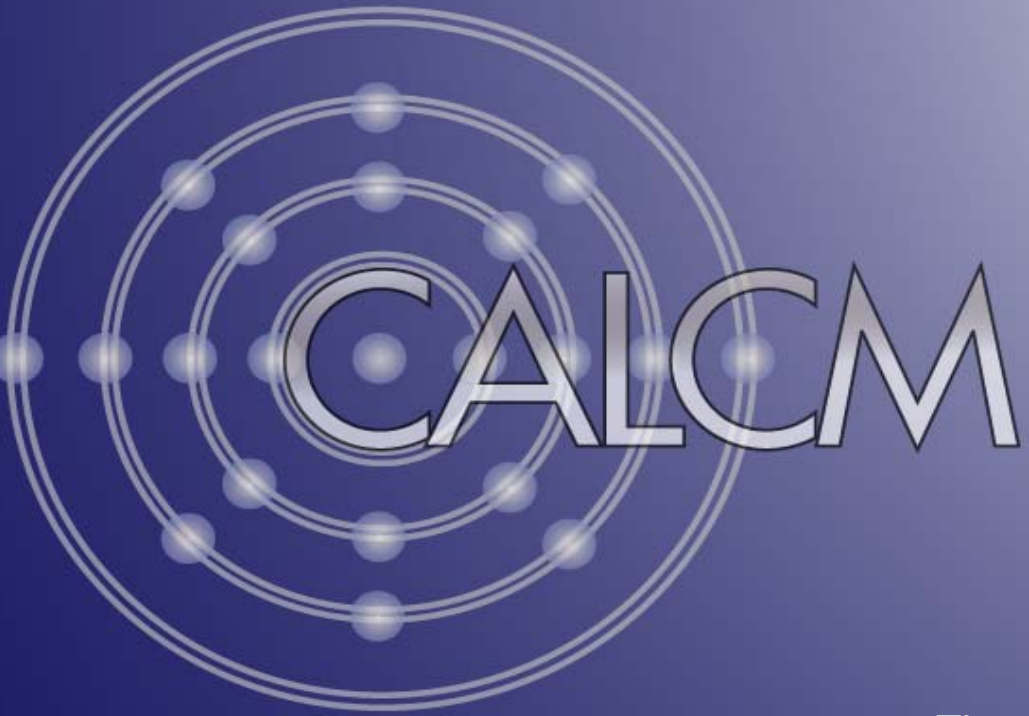

The Computer Architecture Lab at Carnegie Mellon
http://www.ece.cmu.edu/CALCM

Execution Slack & Criticality: Context

- Out of order processors are highly parallel
  - overlap computation
- Technological constraints
  - wire delay, power, complexity
- Non-uniform designs
  - clustering, multi-frequency FU's, memory hierarchies
- Criticality & slack
  - what is it?

Execution Slack & Criticality: Why do I care?

- Exploit to guide control policies
- Examples here do :
  1. Resource Arbitration
  2. Misspeculation Reduction
  3. Power Management
  4. Cache Management

Papers

1. Focusing processor policies via critical-path prediction
   - Framework to identify instruction criticality and design to increase instruction scheduling locality in a cluster
2. Slack: maximizing performance under technological constraints
   - Framework to identify variability in instruction execution criticality and application in slowing down execution to save power
3. Locality vs. Criticality
   - Is sacrificing locality for criticality a good idea?
4. Non-vital loads
   - Identify instructions that can tolerate longer cache hit latencies and remove them from higher-level caches

Evaluation/Outline

- Overview of each technique
- Present results
- Present pros & cons

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Paper 1: Context

- Out of order processors are highly parallel
- Critical-path analysis identifies dominating instructions
  - Micro-architectural critical path
- Focus on optimizing critical instructions
  - Better arbitration of scarce resources
  - Reduce misspeculation

Paper 1: Contributions

- Dependence-graph model of micro-architectural critical path
- Hardware predictor to approximate instruction criticality
- Resource arbitration
- Misspeculation reduction

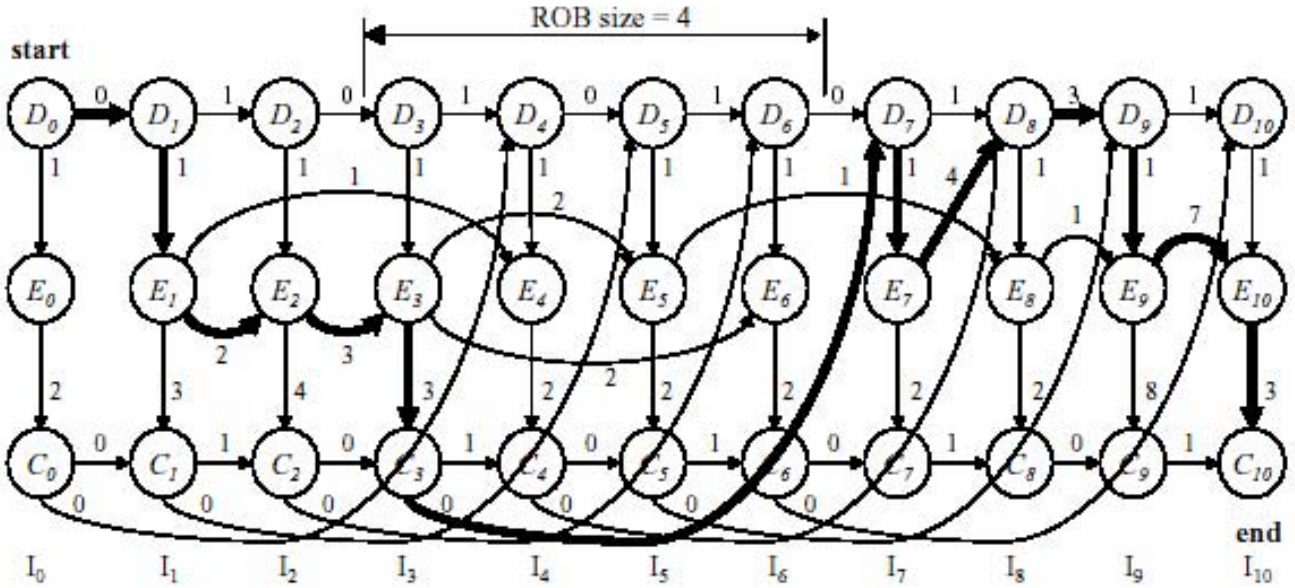
Paper 1: Critical Path Model

name	constraint modeled	edge	
DD	In-order dispatch	$D_{i-1} \rightarrow D_i$	
CD	Finite re-order buffer	$C_{i-w} \rightarrow D_i$	w = size of the re-order buffer
ED	Control dependence	$E_{i-1} \rightarrow D_i$	inserted if $i-1$ is a mispredicted branch
DE	Execution follows dispatch	$D_i \rightarrow E_i$	
EE	Data dependences	$E_j \rightarrow E_i$	inserted if instruction j produces an operand of i
EC	Commit follows execution	$E_i \rightarrow C_i$	
CC	In-order commit	$C_{i-1} \rightarrow C_i$	

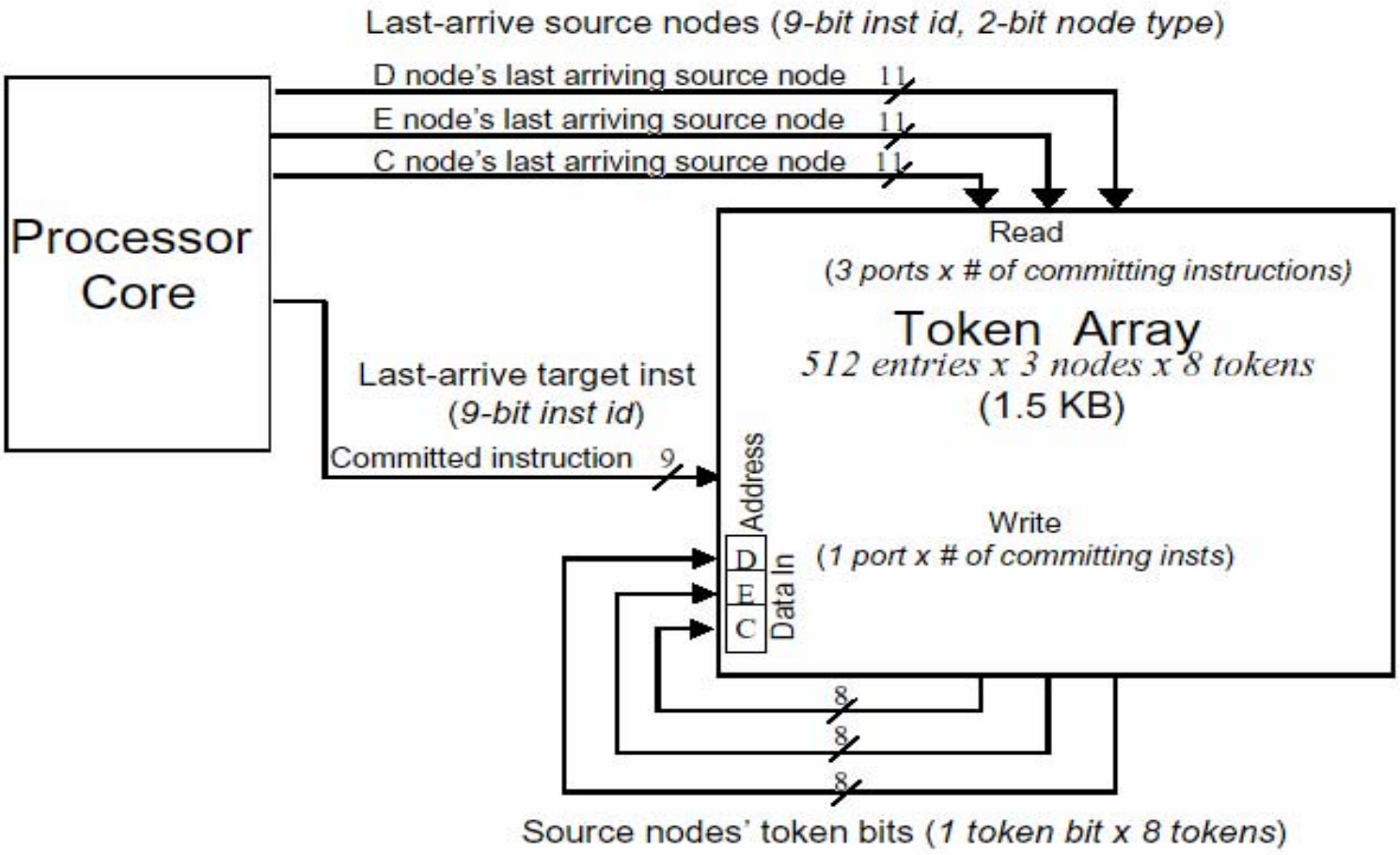
Table 1: **Dependences captured by the critical-path model**, grouped by the target of the dependence.

```
    I0: r5=0
    I1: r3=ld[r2]
L1: I2: r1=r3*6
    I3: r6=ld[r1]
    I4: r3=r3+1
    I5: r5 = r6 + r5
    I6: cmp R6,0
    I7: br L1
    I8: r5 = r5+100
    I9: r0 = r5 / 3
   I10: Ret r0
```

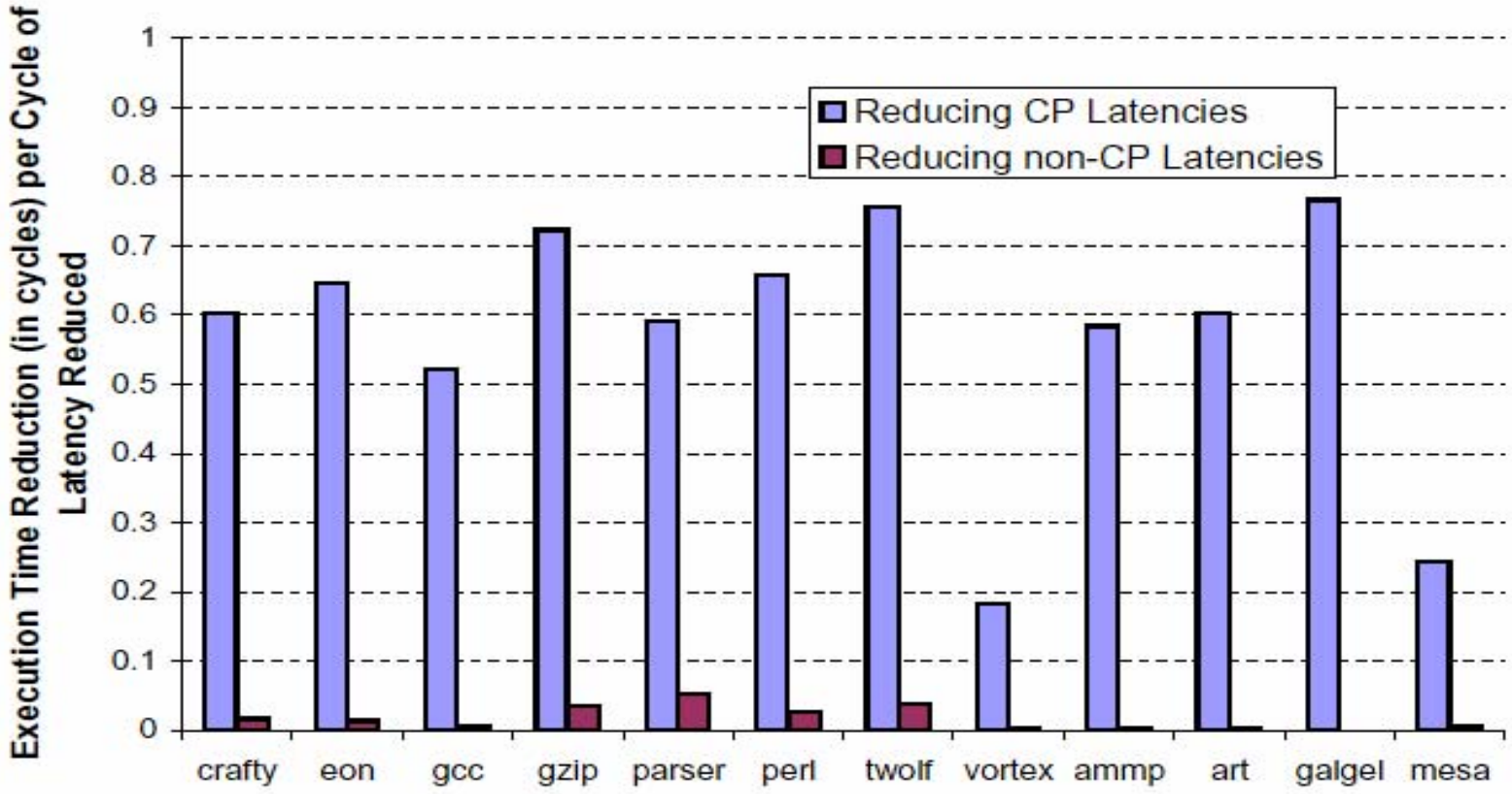
Dynamic Inst. Trace



Paper 1: Hardware

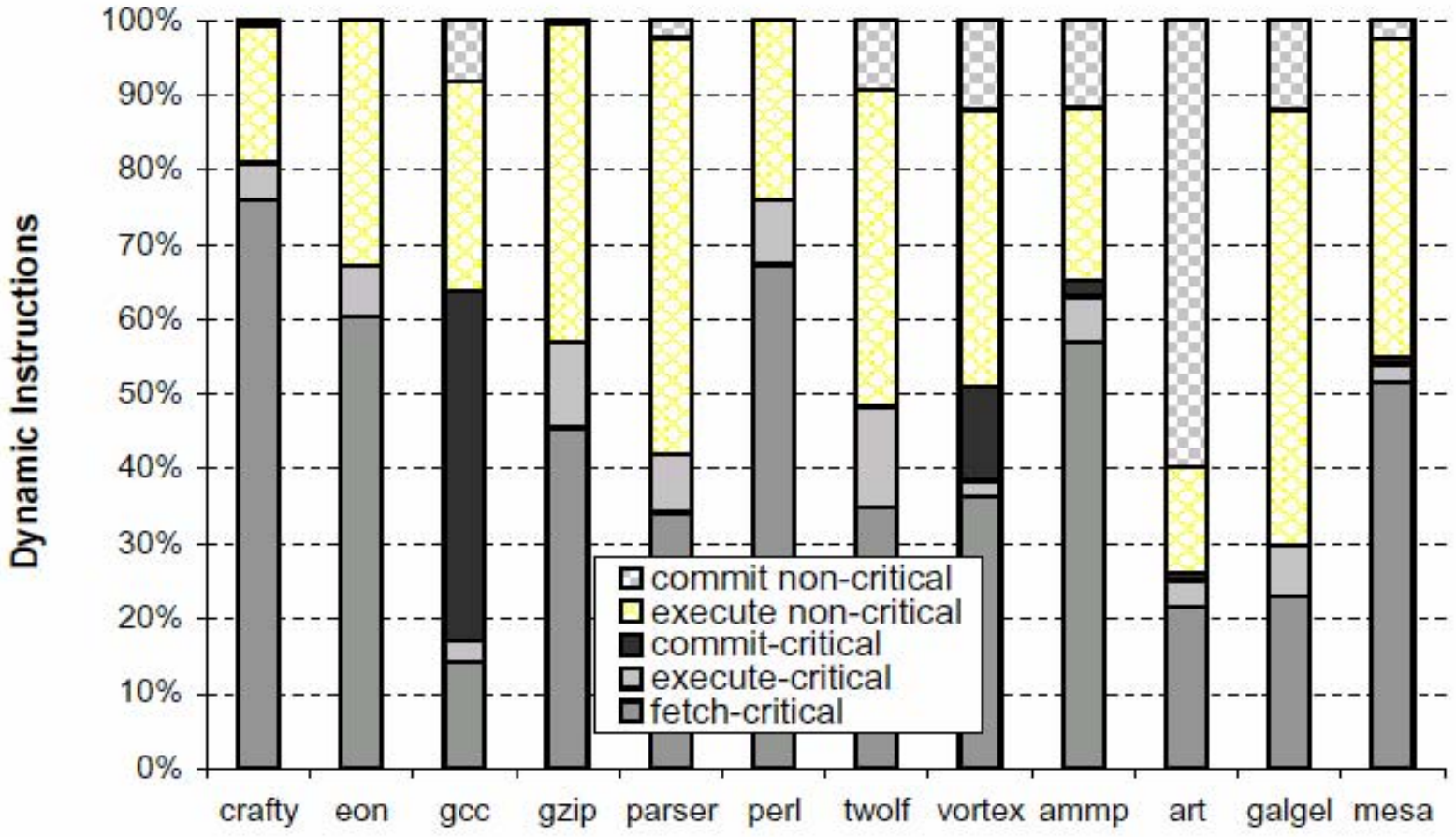


Paper 1: Model Evaluation



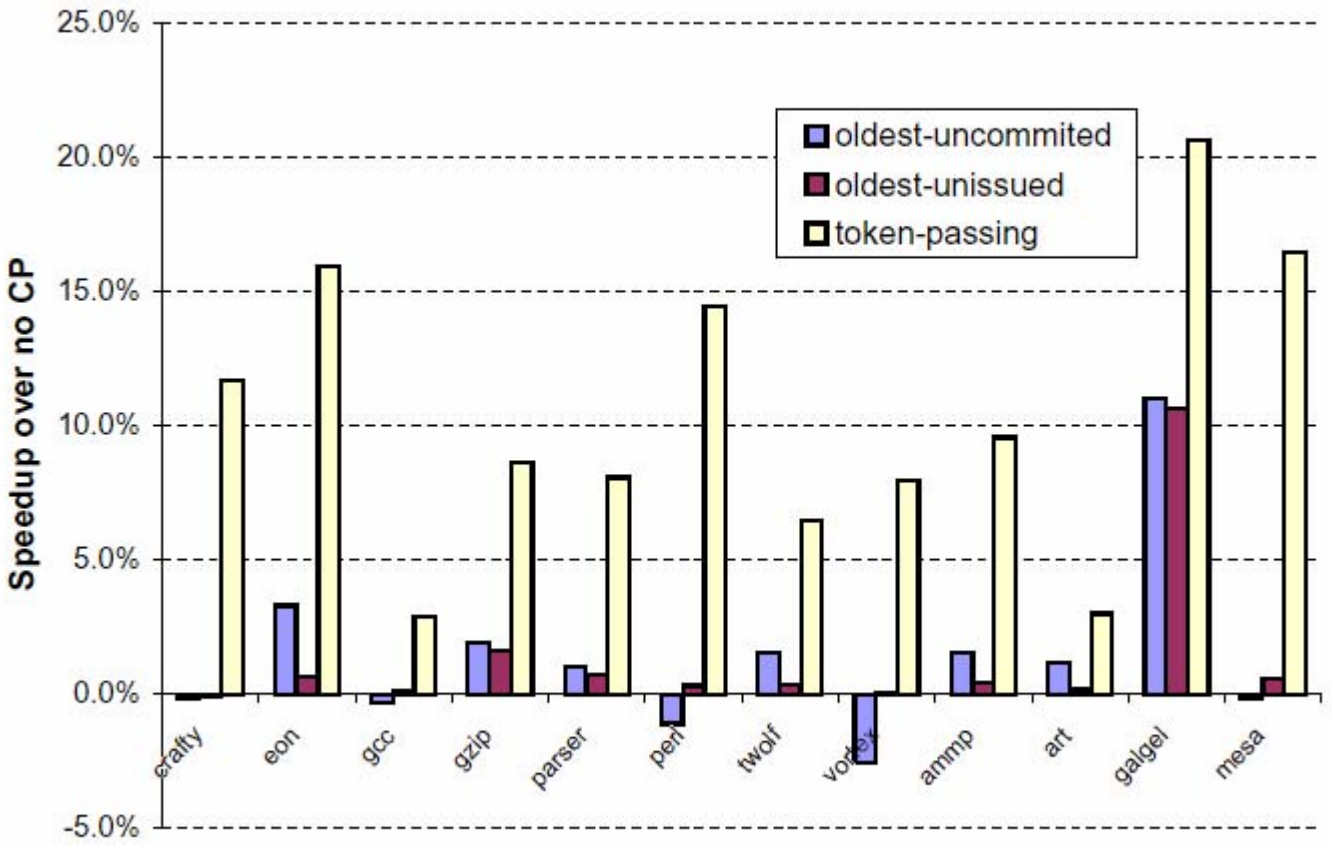
(a) Validation of the critical-path model.

Paper 1: Model Evaluation



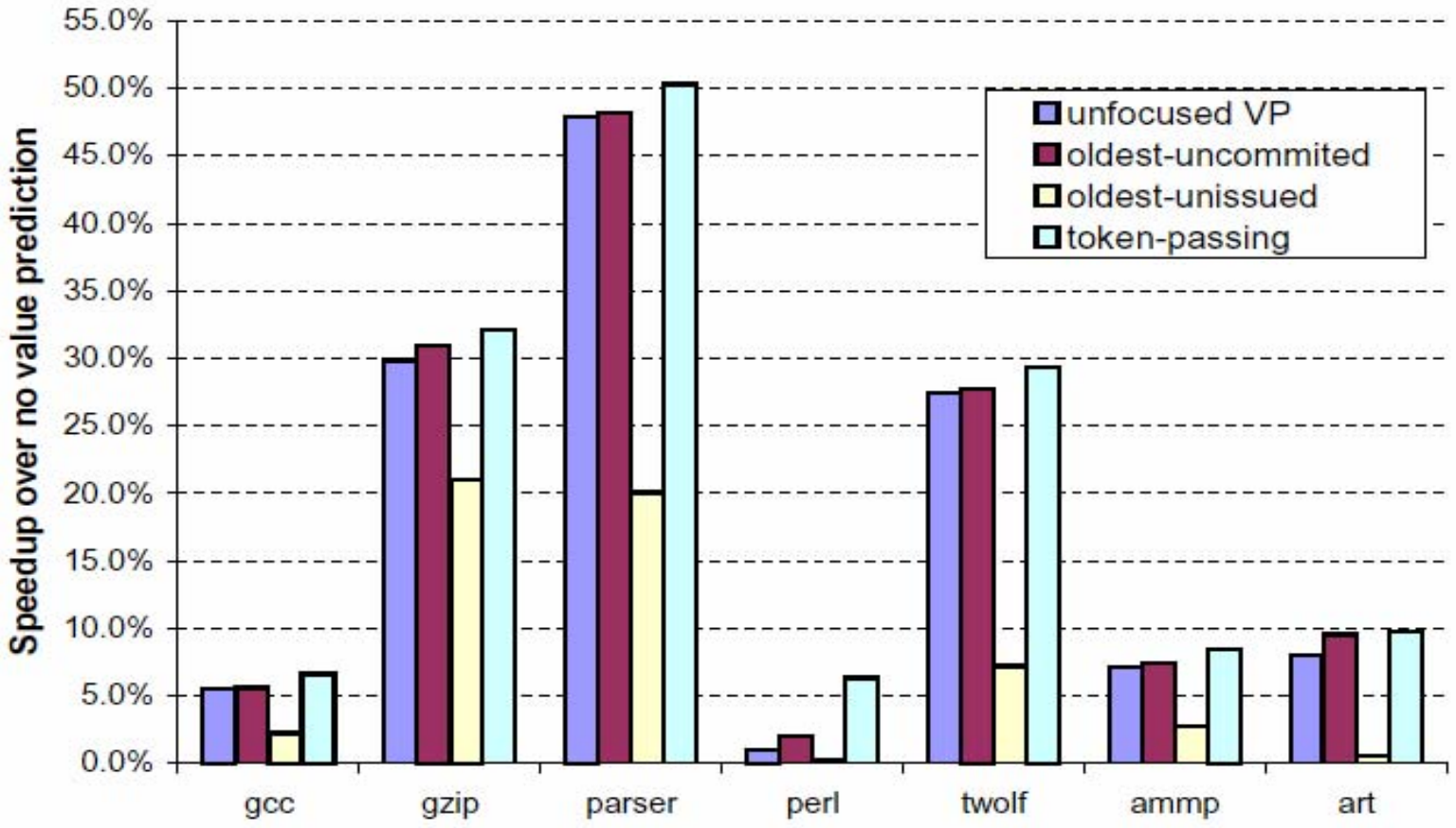
(b) Breakdown of the dynamic instruction count.

Paper 1: Instruction Scheduling and Steering



(b) Comparison to heuristics-based predictors.

Paper 1: Value Prediction



(b) Speedup of focused value prediction.

Paper 1: Critique

Prons

- Multipurpose framework
- Adaptive
- Practical algorithmic approach
- Yields interesting results

Cons

- Wrong path instructions, criticality at memory system ?
- Coarse
- Classification imbalance
- Practical hardware realization

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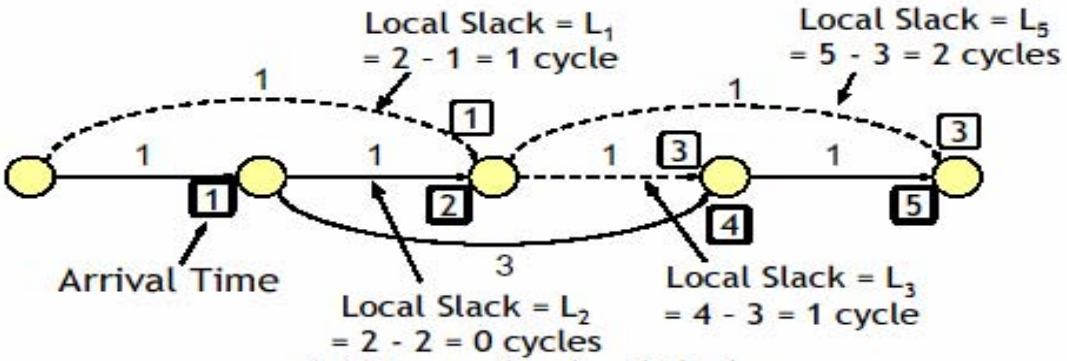
Paper 2: Context

- Technological constraints
  - wire delay, power, complexity
- Non-uniform designs
  - clustering, multi-frequency FU's
- Control policies
- Slack

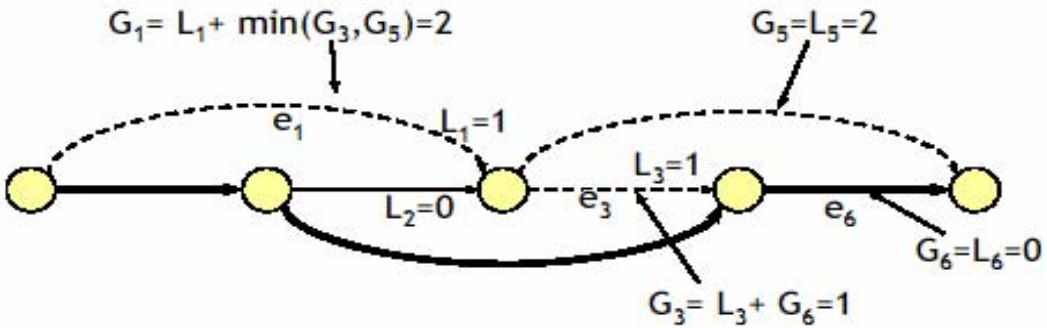
Paper 2: Contributions

- Model and characterize slack
  - local, global, apportioned
- Slack prediction
  - explicit, implicit
- Application in power saving hardware
  - fast/slow pipeline

Paper 2: Computing Slack

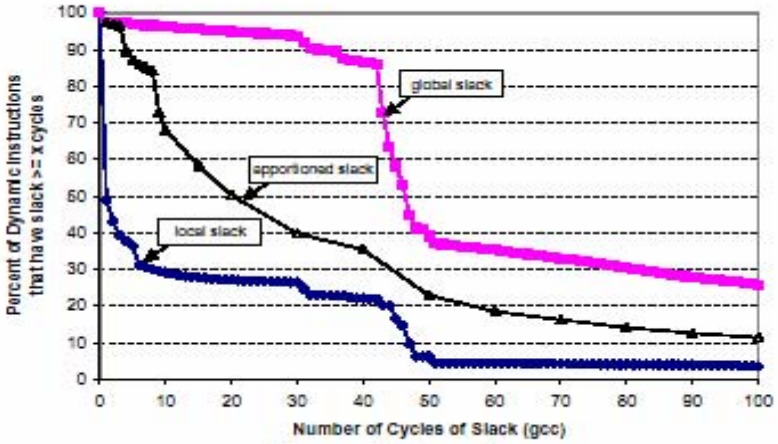


(a) Computing local slack.

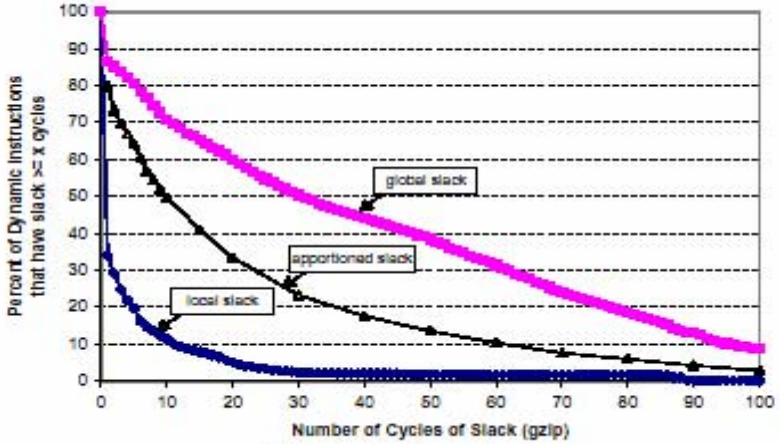


(b) Computing global slack.

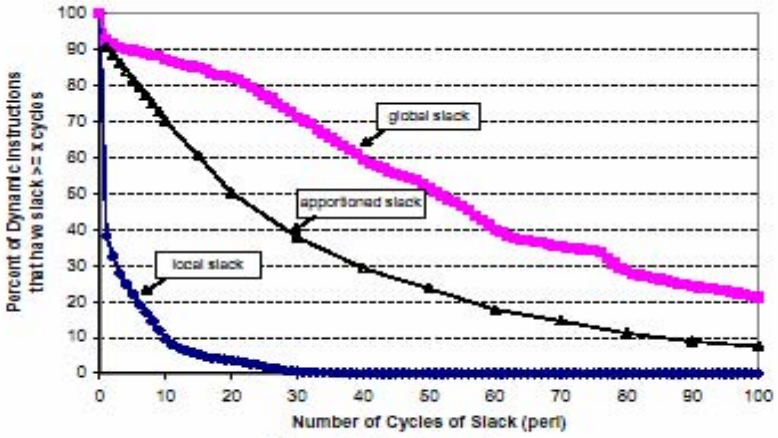
Paper 2: Slack Potential



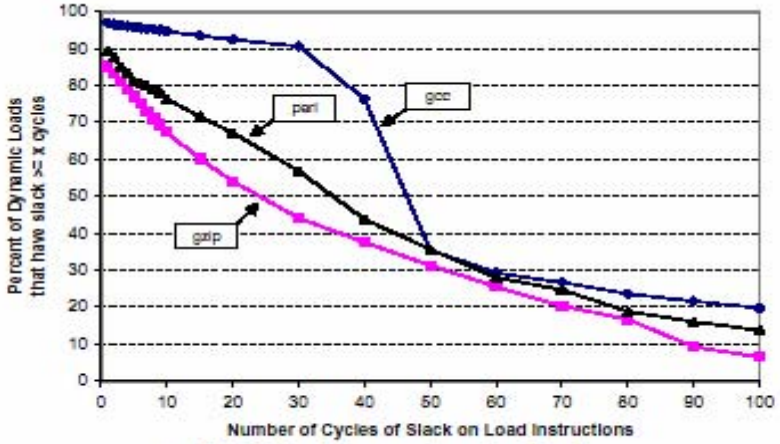
(a) *gcc* slack results.



(b) *gzip* slack results.

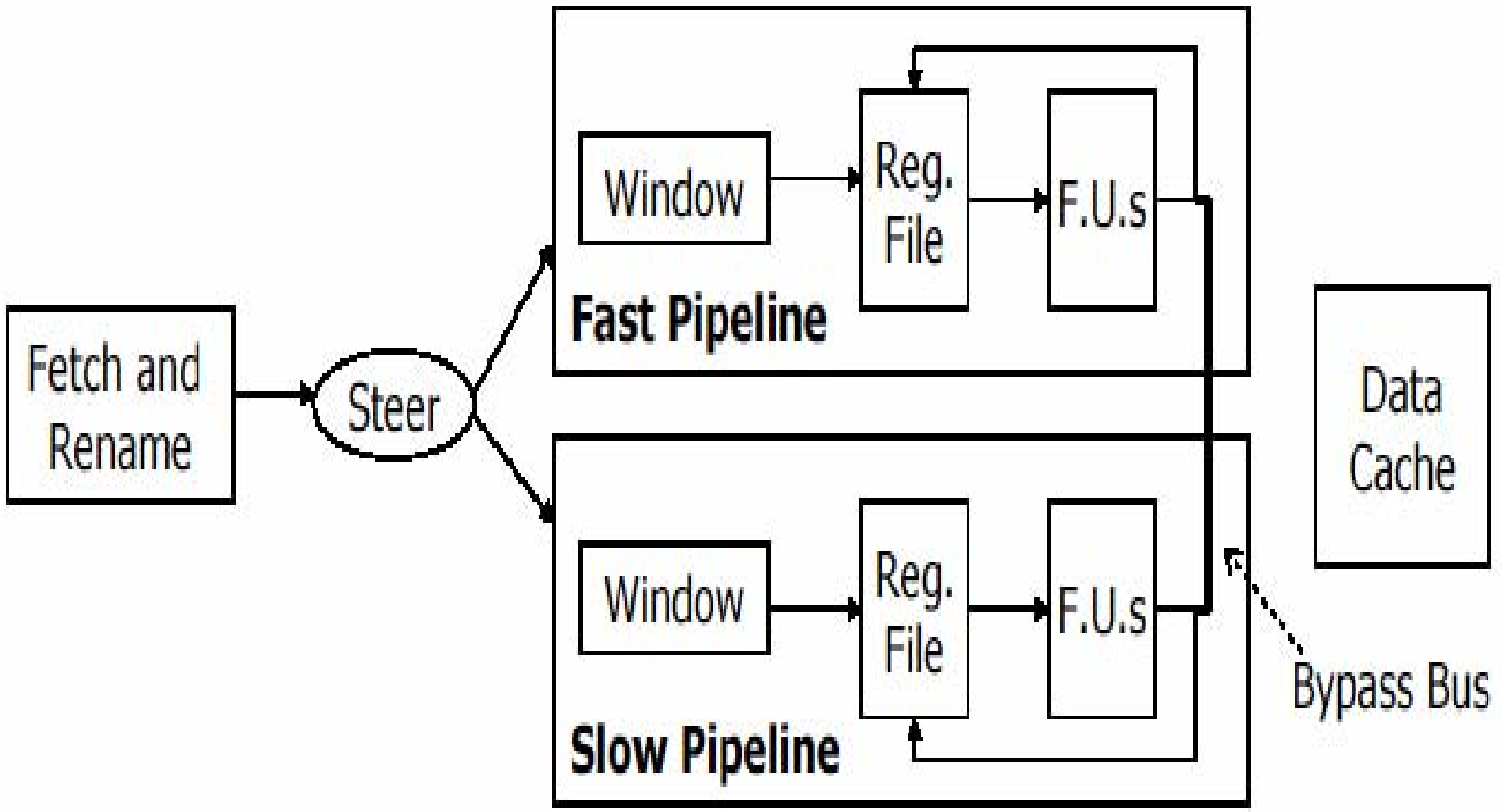


(c) *perl* slack results.

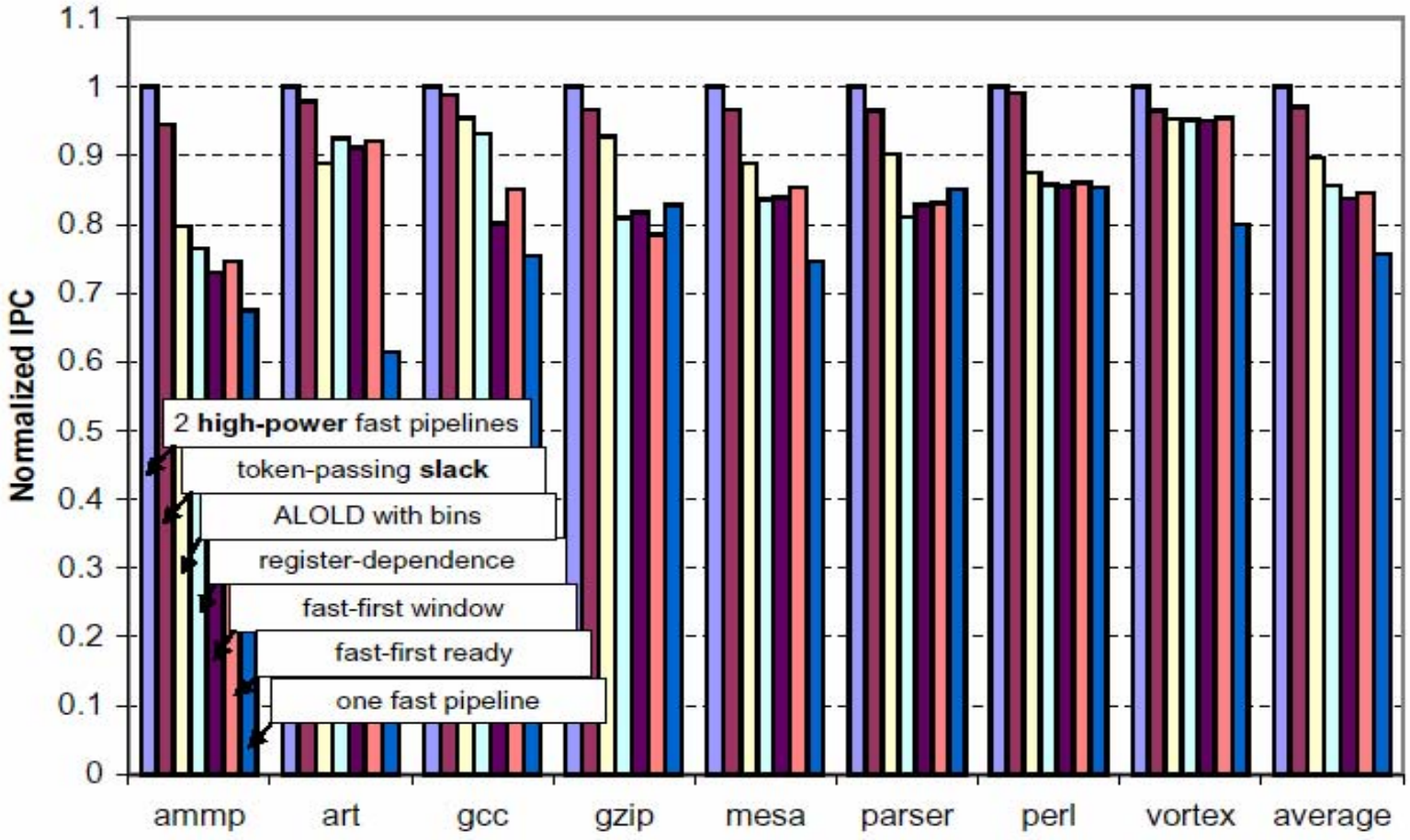


(d) All slack apportioned to loads.

Paper 2 : Microarchitecture



Paper 2: Performance Impact



Paper 2: Critique

Prons:

- Easy to reason
- Adaptive
- Fine grained

Cons

- Sampling constraints
- Criticality at memory system ?
- Weakly defined apportioned slack

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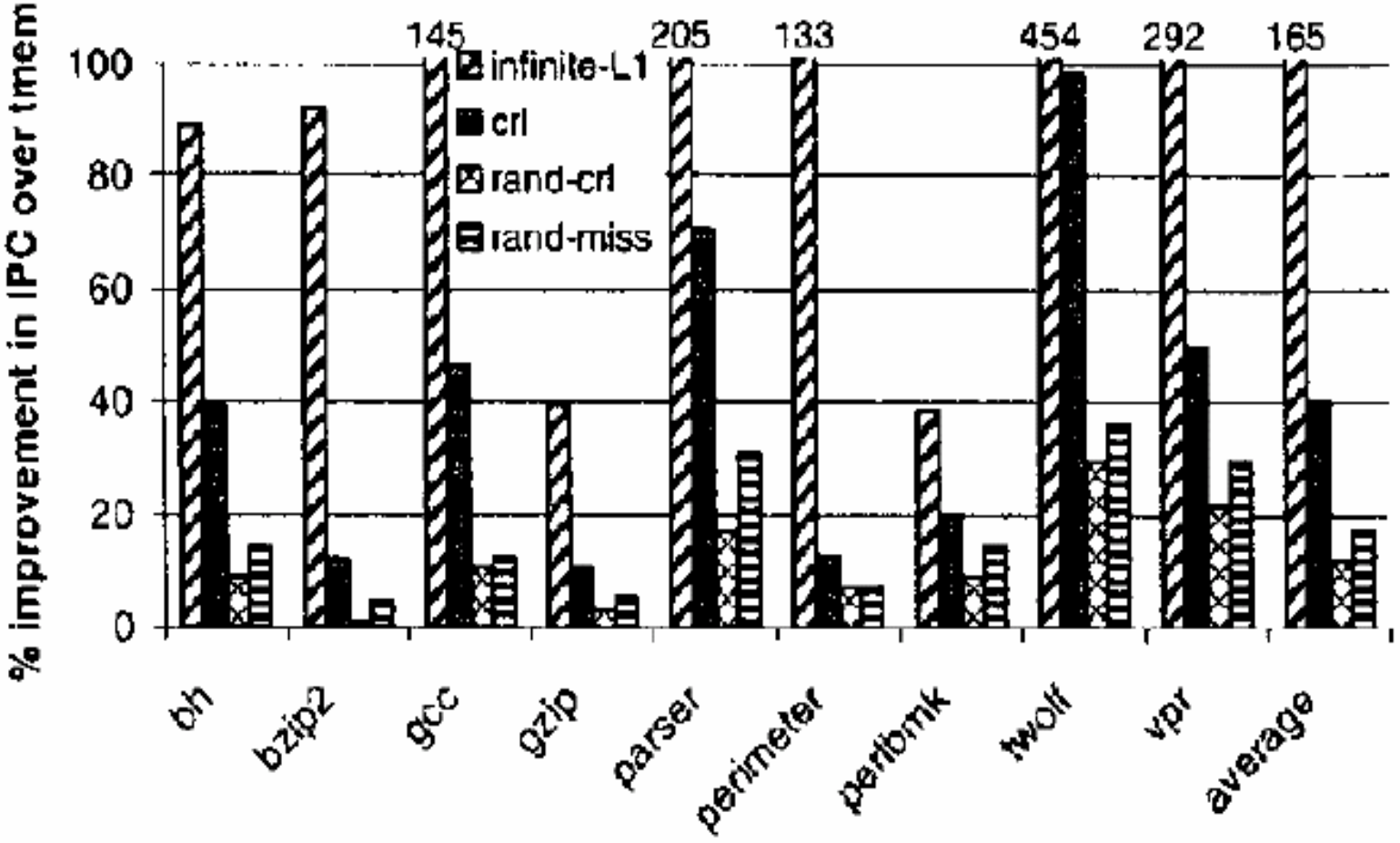
Paper 3: Context

- Caches exploit spatial and temporal locality
- Locality based schemes ignore nature of misses
- Is criticality a strong enough property to warrant a change in memory hierarchies?
- Classify loads as critical
  - feed mispredicted branch, feed into missed load, few independent instructions following

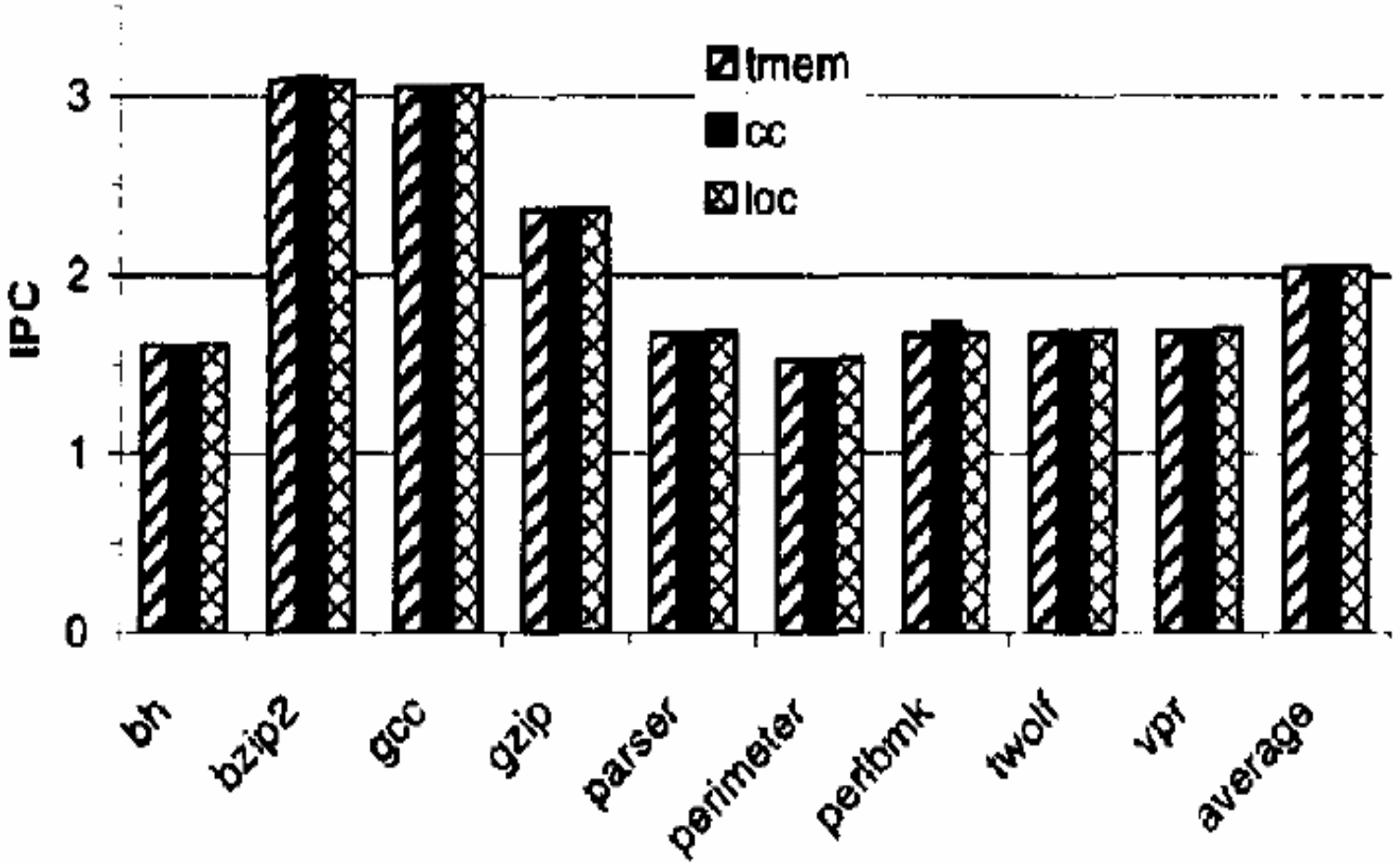
Paper 3: Contributions

- Provides an answer to the question posed
  - Potential is there
  - Implementations fail

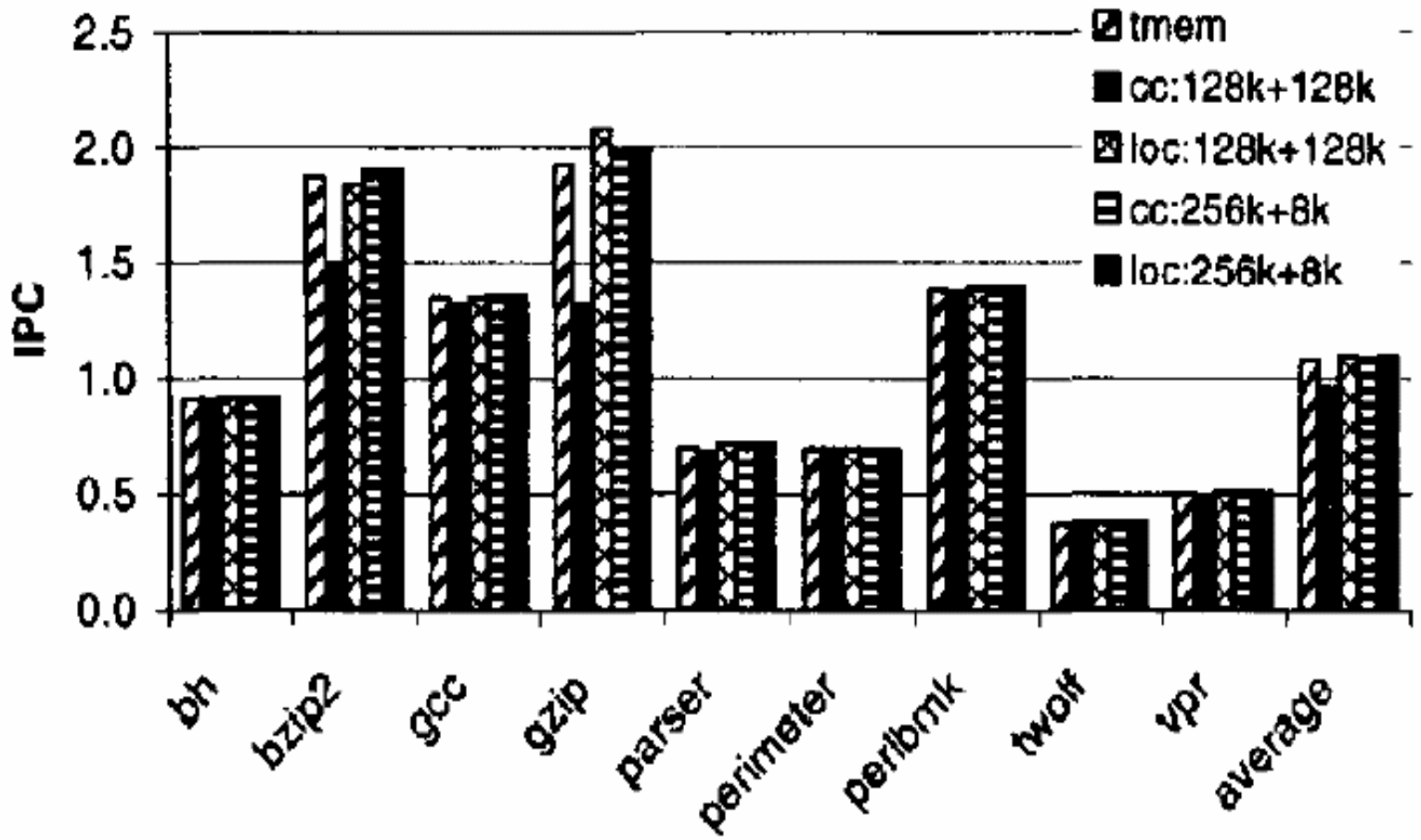
Paper 3: L1 Criticality Potential



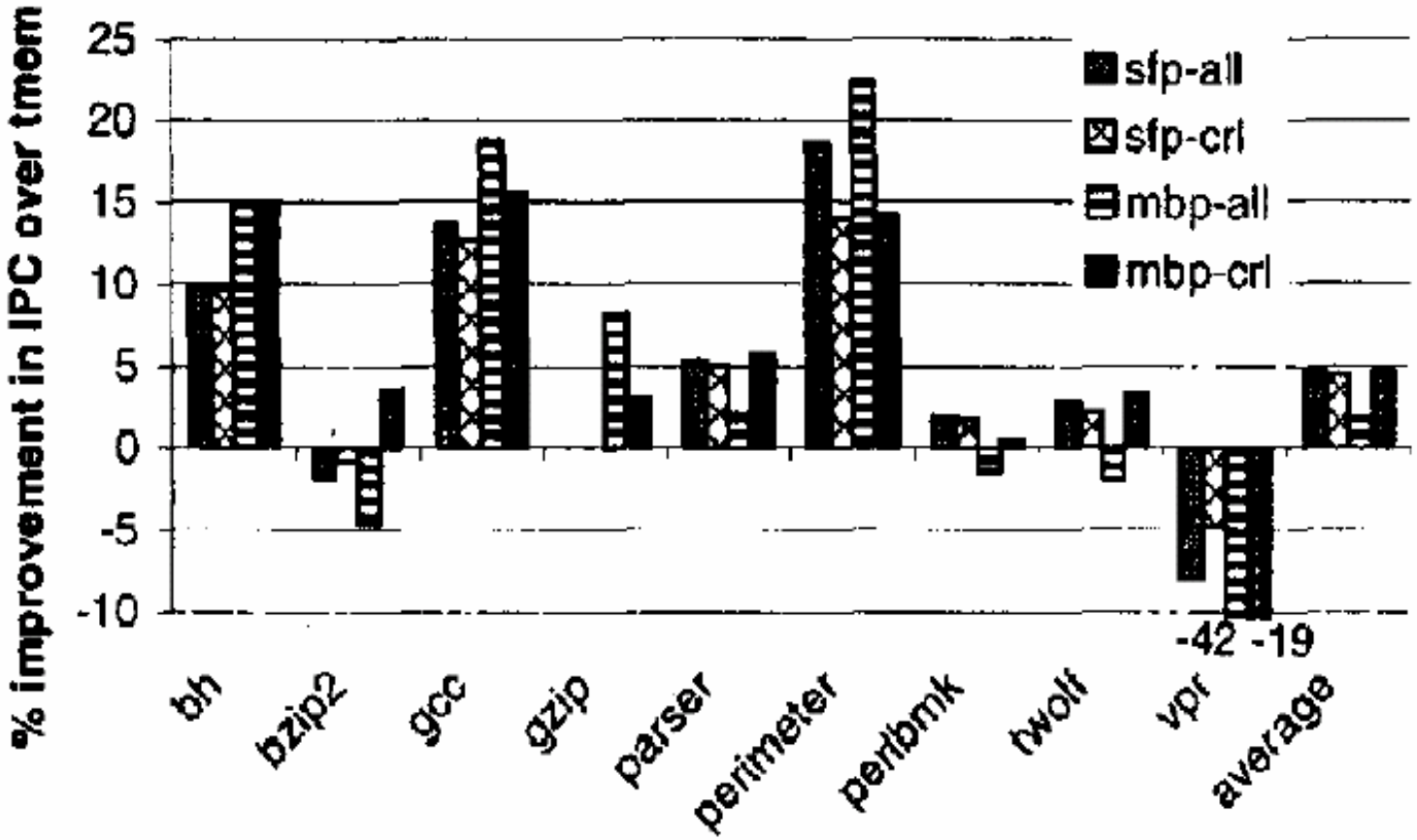
Paper 3: Exploiting L1 Criticality



Paper 3: Exploiting L2 Criticality



Paper 3: Criticality Guided Prefetching



Paper 3: Critique

Prons

- Raises important question
- Provides a limit study: the potential is there

Cons

- Is classification really complete?
- Coverage?
- Accuracy?

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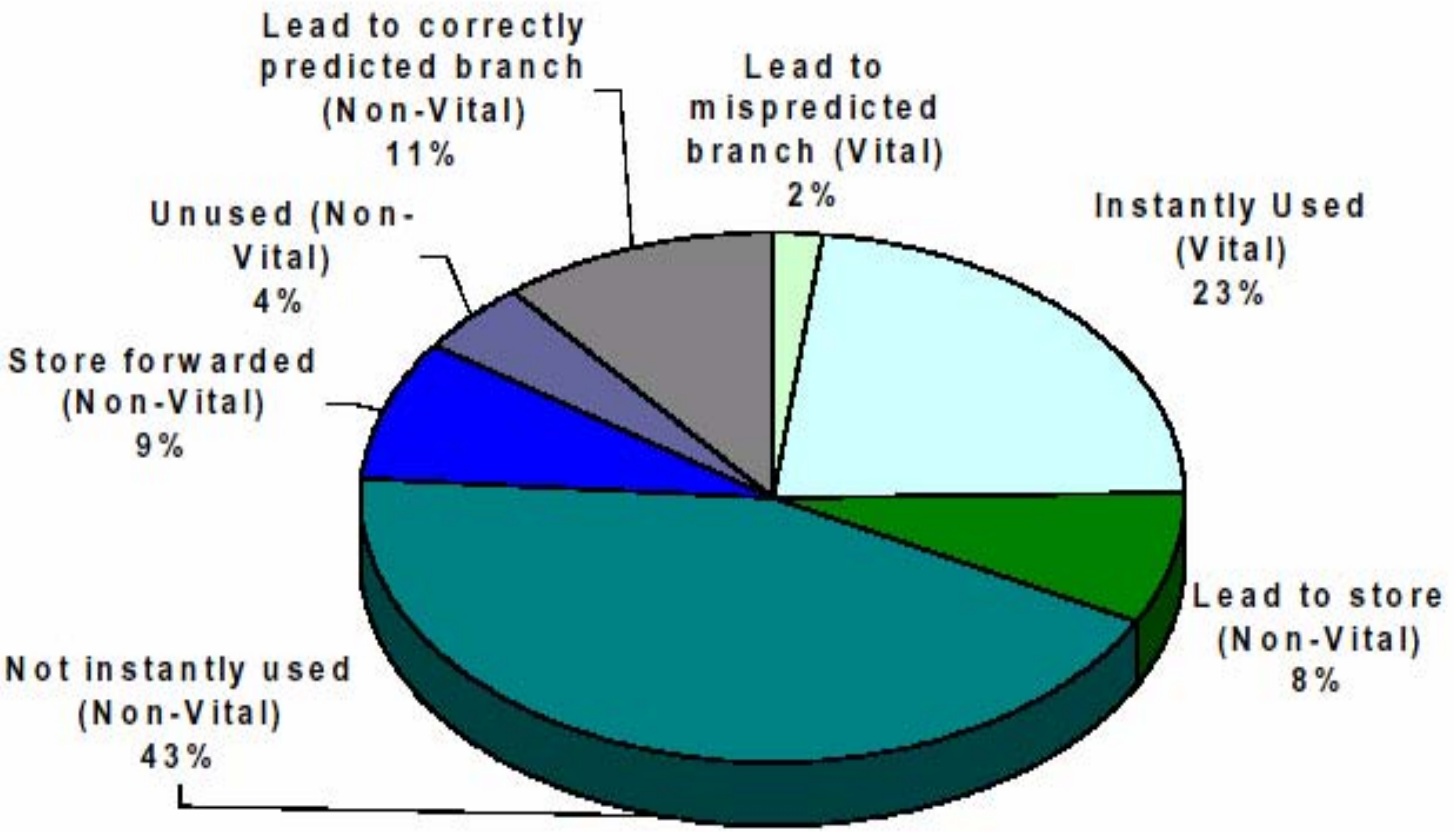
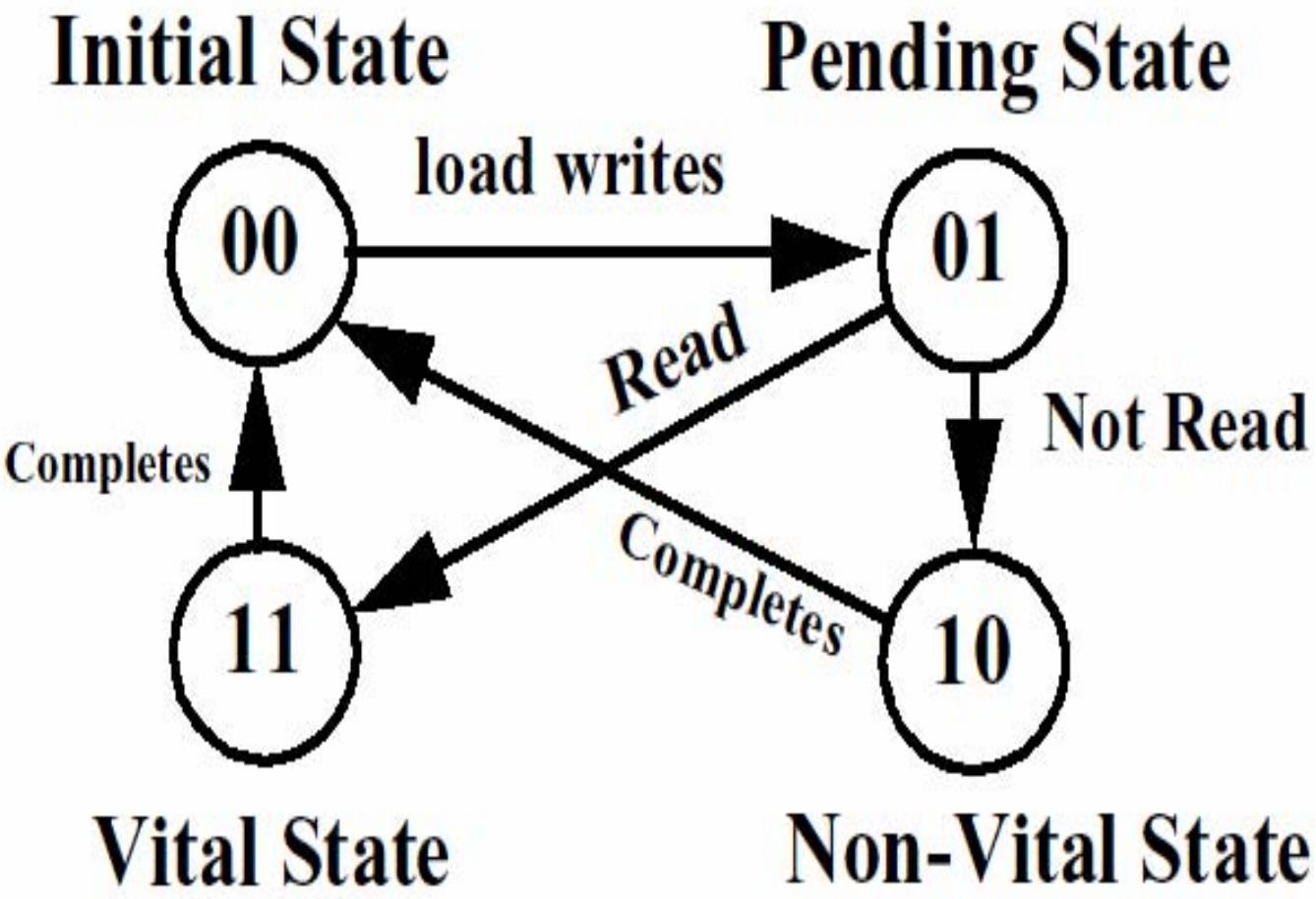
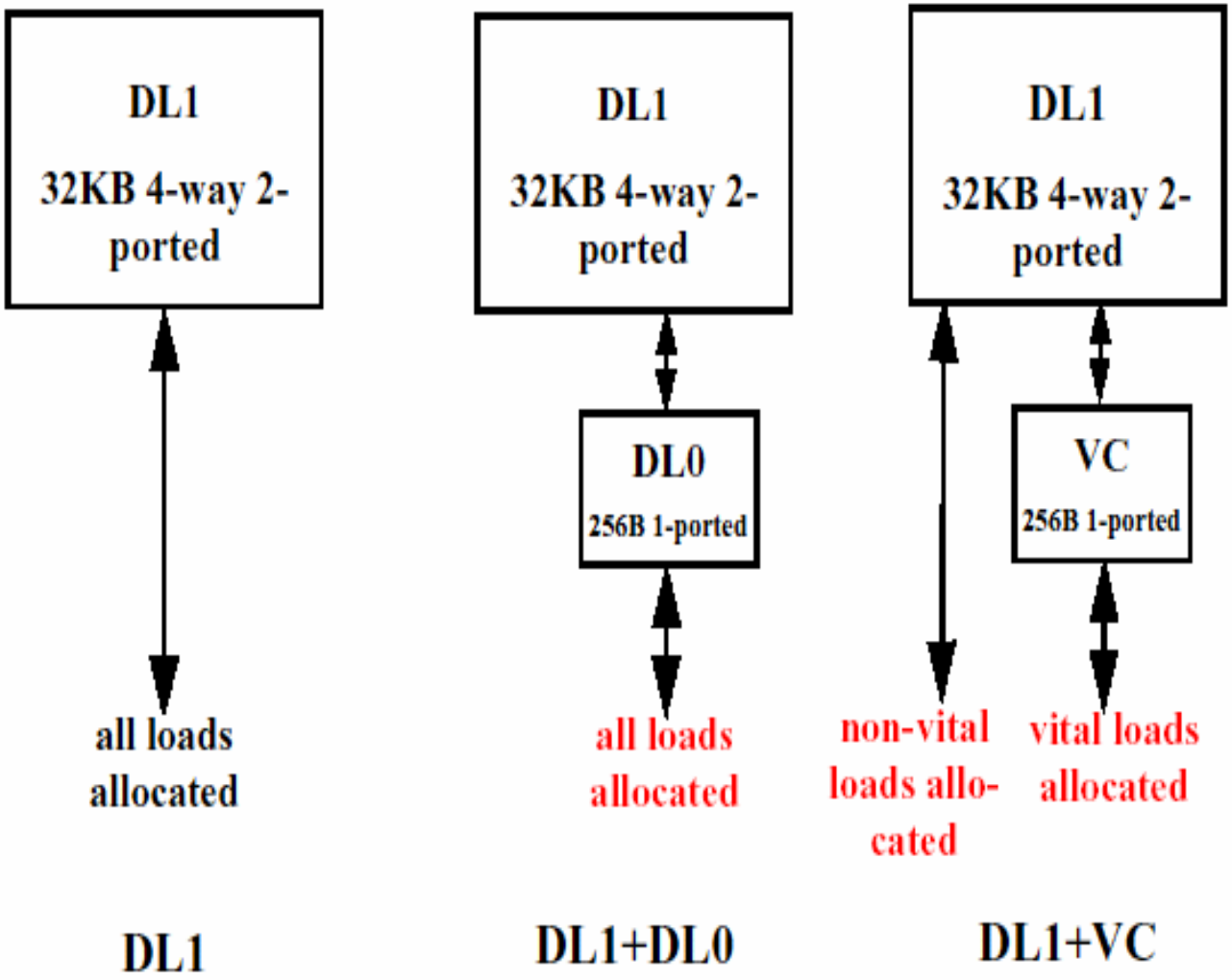
Paper 4: Load Classification



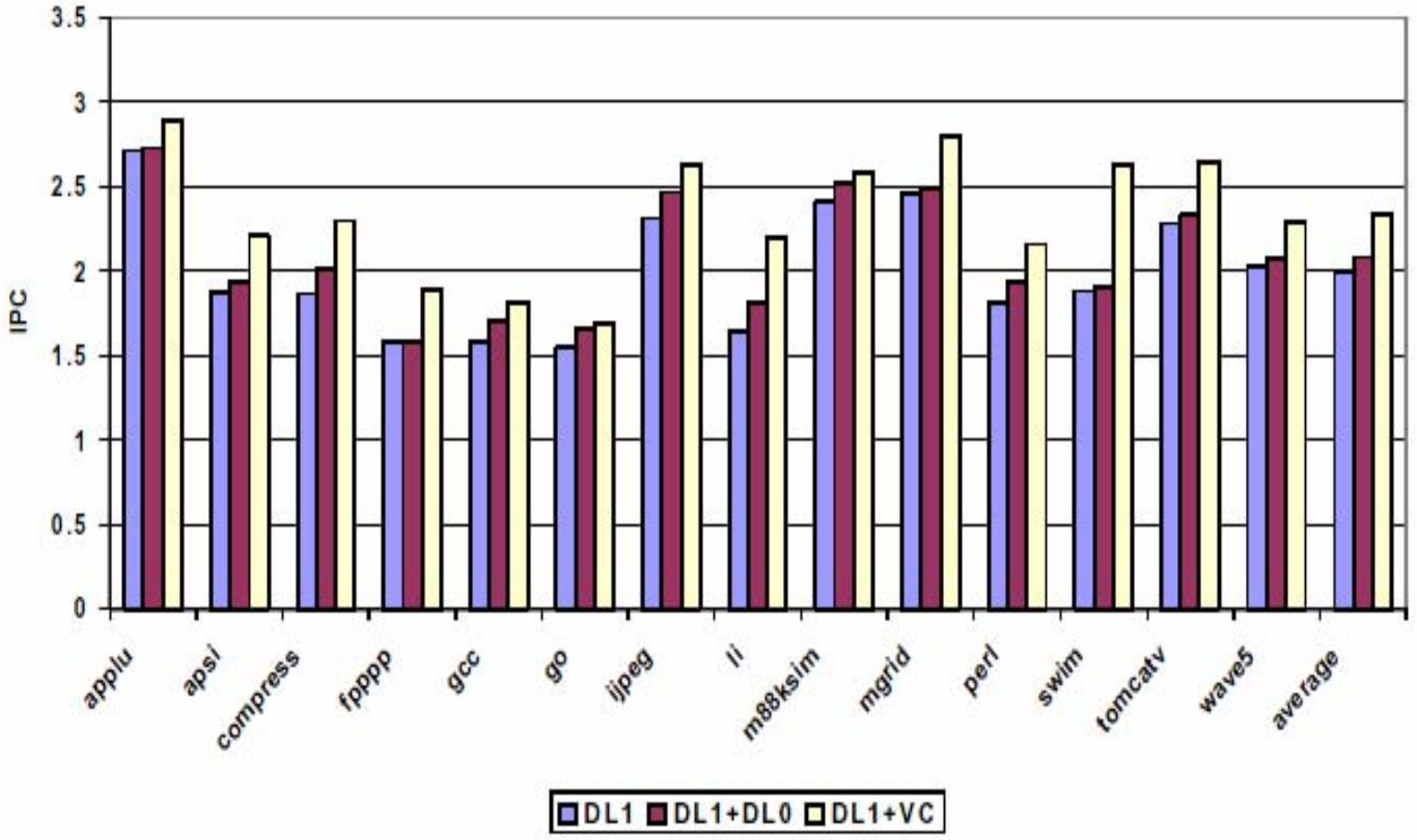
Paper 4: Classification FSM



Paper 4: Cache Hierarchy



Paper 4: Evaluation



Paper 4: Critique

Prons

- Vital Cache improves performance
- Shows more promise than previous paper

Cons

- Does not explore slack
- Still need an optimality study

Summary

- Criticality and Slack can be exploited to guide policies
- Correct classification is key
- Are hardware implementations practical?
- Criticality at the memory system is still challenging
  - Should we give up hope?