Informed Microarchitecture Design Space Exploration Using Workload Dynamics

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(MICRO-40)

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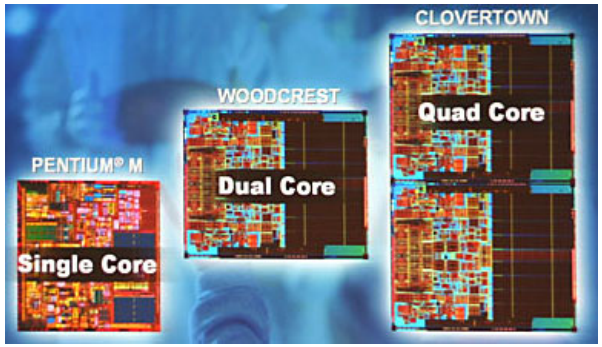
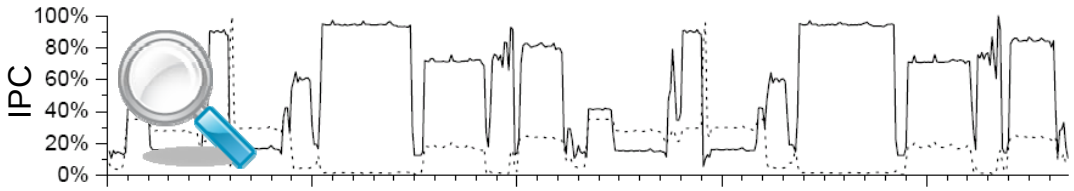
Motivation

- Workload dynamics prediction



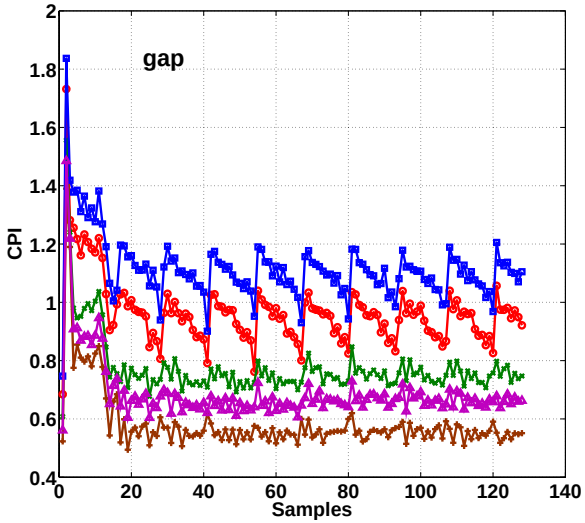


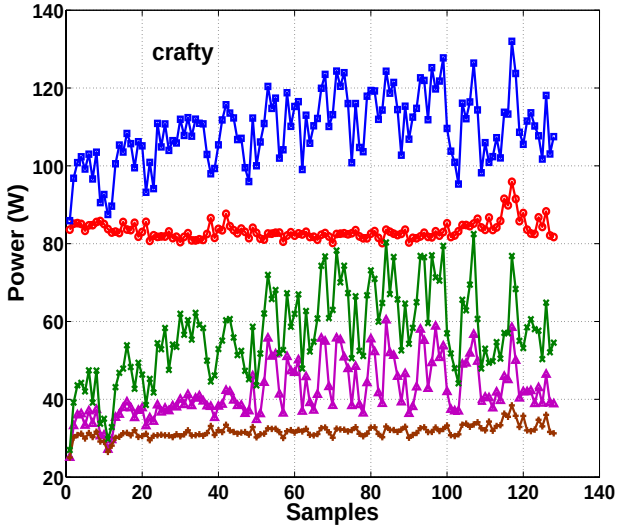
- Workload dynamics prediction for worst-case scenario

Ref: http://www.geekstogo.com, http://eazyvg.wordpress.com

Introduction

- Workload dynamic variations





- Slow, detailed simulation

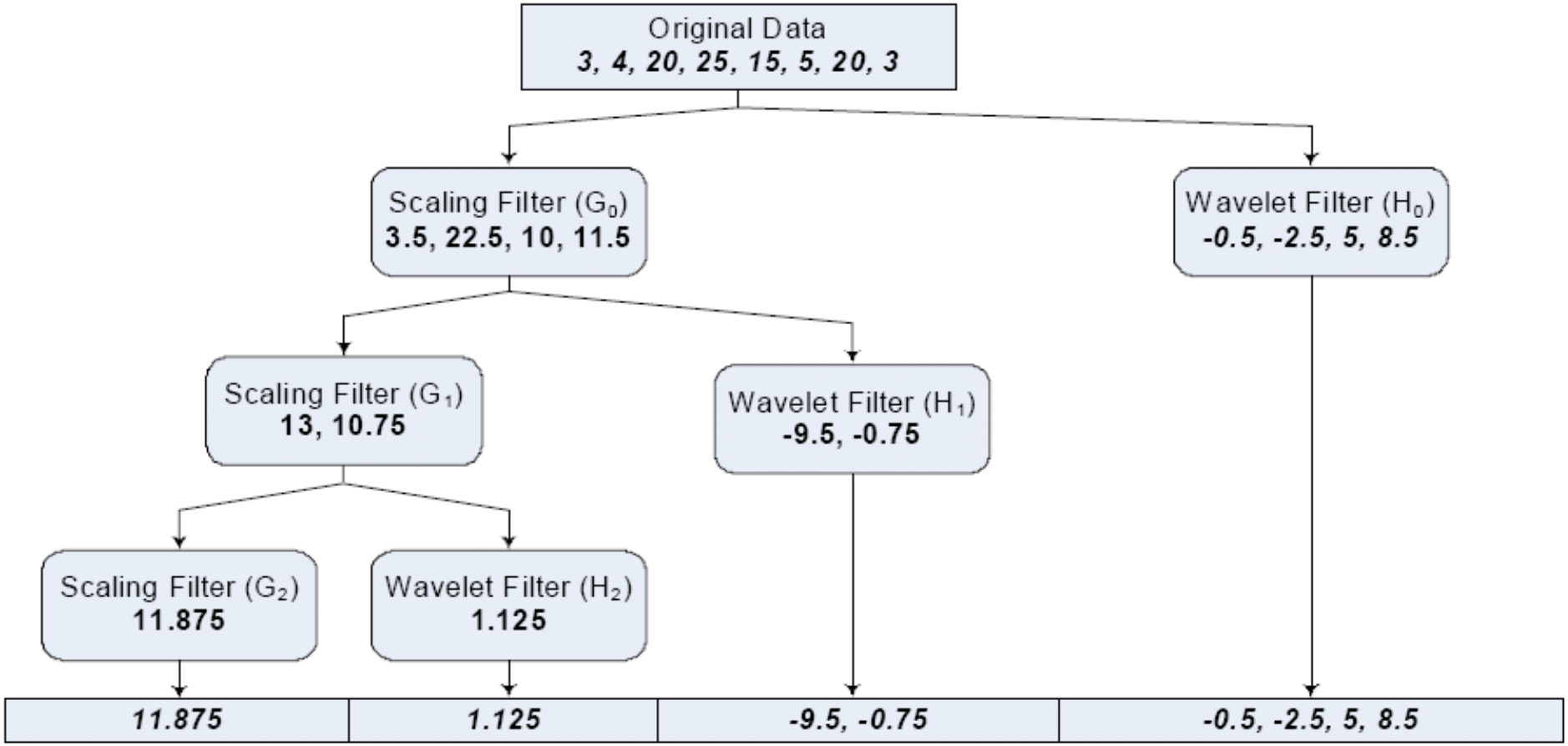
Previous research

- Sherwood (ASPLOS ’02)
  - Phase analysis and Simpoint
- Lee (ASPLOS ’06)
  - Linear regression model
- Ipek (ASPLOS ’06)
  - Neural network model
- Joseph(HPCA ’06, MICRO ’06)
  - Linear and non-linear predictive models

Contributions

- Build accurate and informative predictive models
  - Combine the wavelet and neural network
- Evaluate efficiency
  - Performance, power and reliability domains
- Present case studies
  - Scenario-aware prediction
  - DVM (Dynamic Vulnerability Management)

Background : wavelet transform (1/3)



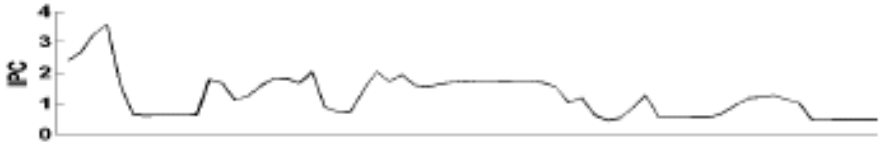
Haar wavelet transform ->

Scaling filter = (even+odd)/2

Wavelet filter = (even-odd)/2

Background : wavelet transform (2/3)

- Workload behavior can be represented at different scales using wavelet transform

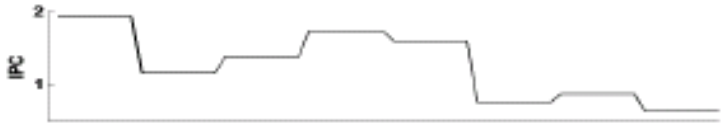


Time domain program behavior (64 samples)

(a) 1 wavelet coefficient

(b) 2 wavelet coefficients

(c) 4 wavelet coefficients

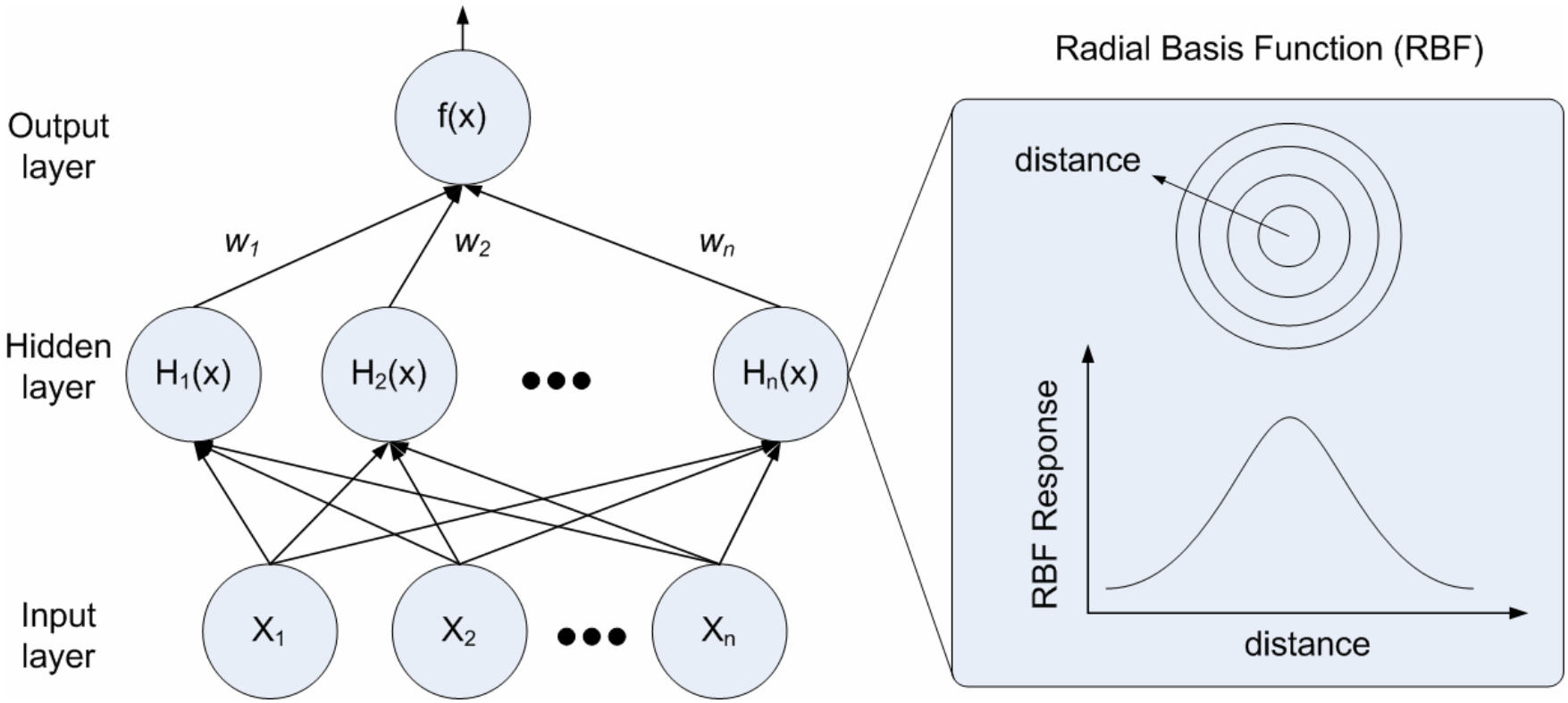


(d) 8 wavelet coefficients

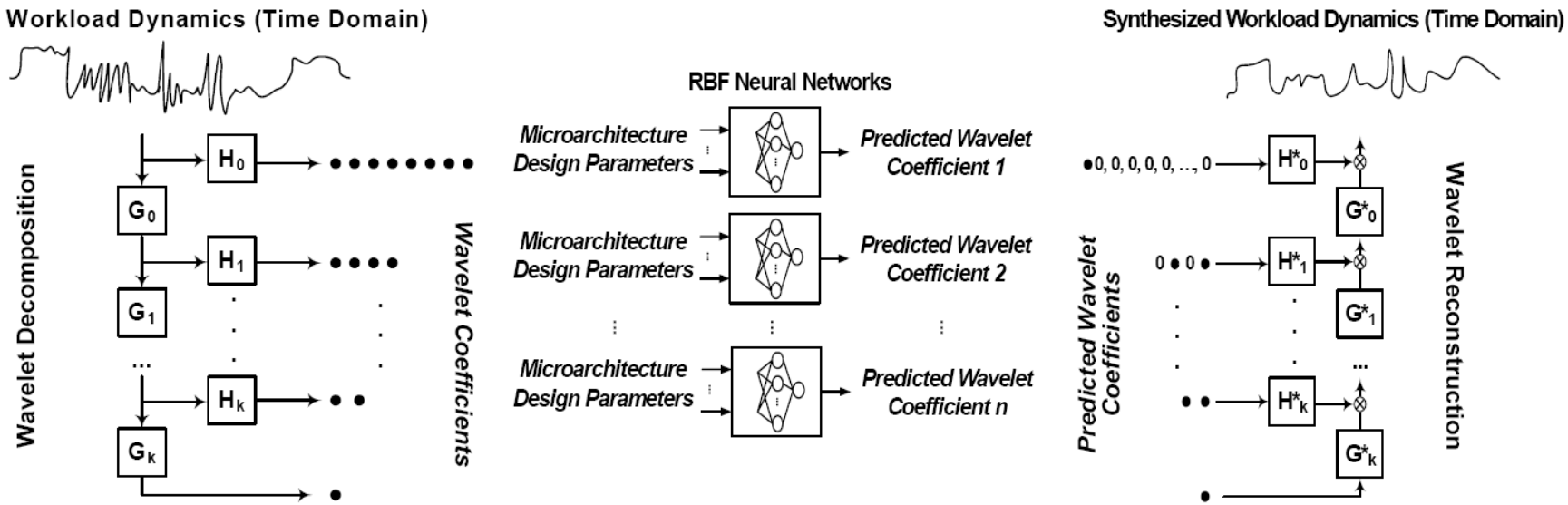
(e) 16 wavelet coefficients

(f) 64 wavelet coefficients

Background : neural network (3/3)



Combining wavelet and NN



- Wavelet decomposition of workload behavior
- Wavelet coefficients are predicted by NNs
- Reconstruct workload behavior using predicted wavelet coefficients

Experimental setup

- Benchmarks (SPEC CPU 2000)
  - bzip2, crafty, eon, gap, gcc, mcf, parser, perlbmk, swim, twolf, vortex and vpr
- Metrics
  - Performance (CPI)
  - Power (Wattch-based model)
  - Reliability (Architectural Vulnerability Factor: AVF)

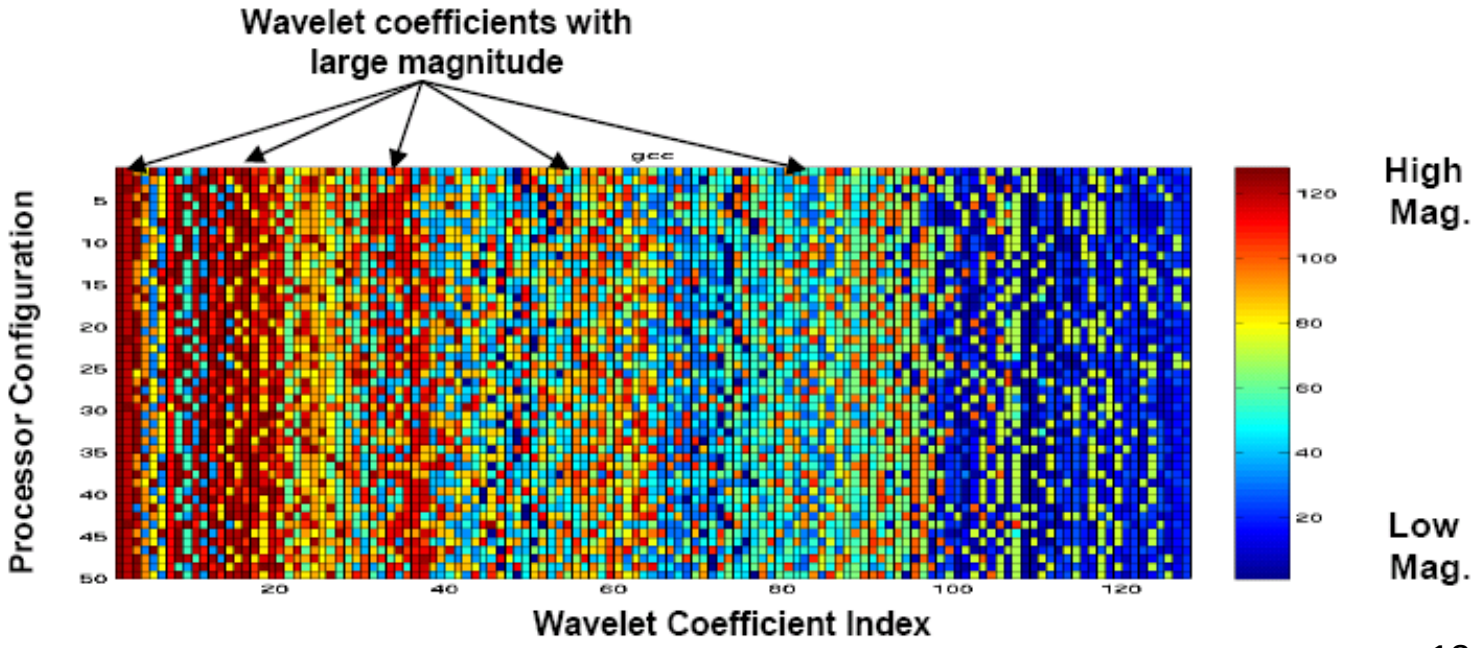
Explore the design space

Parameter	Ranges		# of Levels
	Train	Test	
Fetch_width	2, 4, 8, 16	2, 8	4
ROB_size	96, 128, 160	128, 160	3
IQ_size	32, 64, 96, 128	32, 64	4
LSQ_size	16, 24, 32, 64	16, 24, 32	4
L2_size	256, 1024, 2048, 4096 KB	256, 1024, 4096 KB	4
L2_lat	8, 12, 14, 16, 20	8, 12, 14	5
il1_size	8, 16, 32, 64 KB	8, 16, 32 KB	4
dl1_size	8, 16, 32, 64 KB	16, 32, 64 KB	4
dl1_lat	1, 2, 3, 4	1, 2, 3	4

- 9 microarchitectural parameters
- LHS(Latin Hypercube Sampling) + L2-star discrepancy

Selecting wavelet coefficients

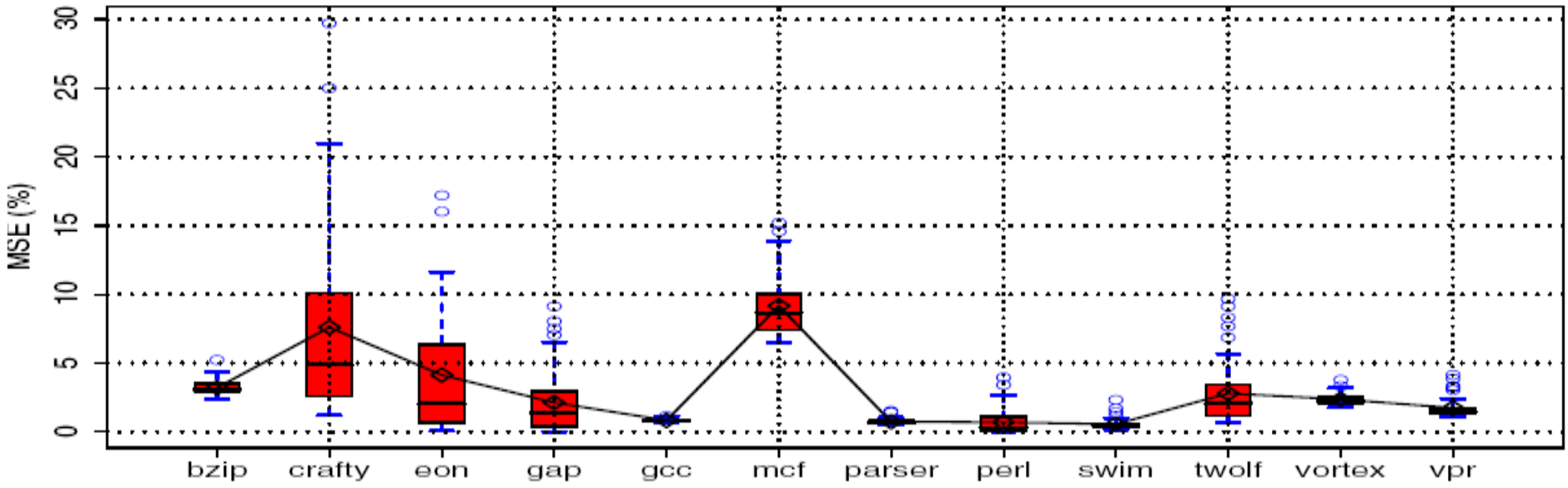
- Order-based wavelet coefficients
  - Select first *k* coefficients
- Magnitude-based wavelet coefficients
  - Select the largest *k* coefficients



Evaluation : MSE

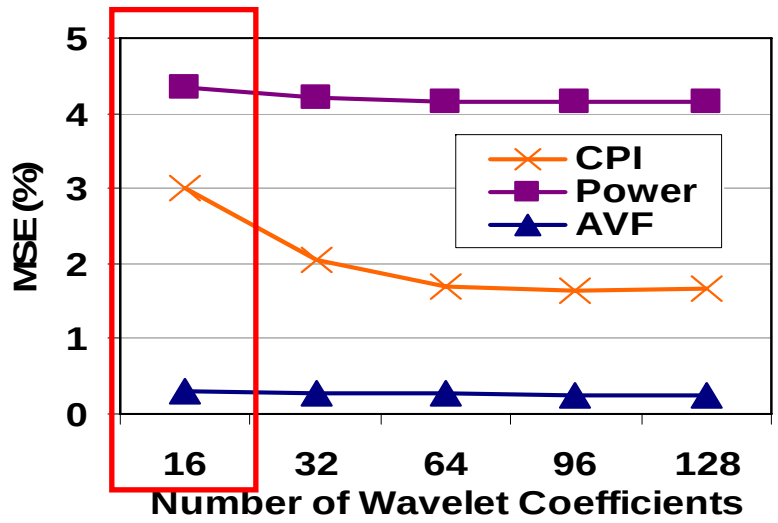
- Mean Square Error

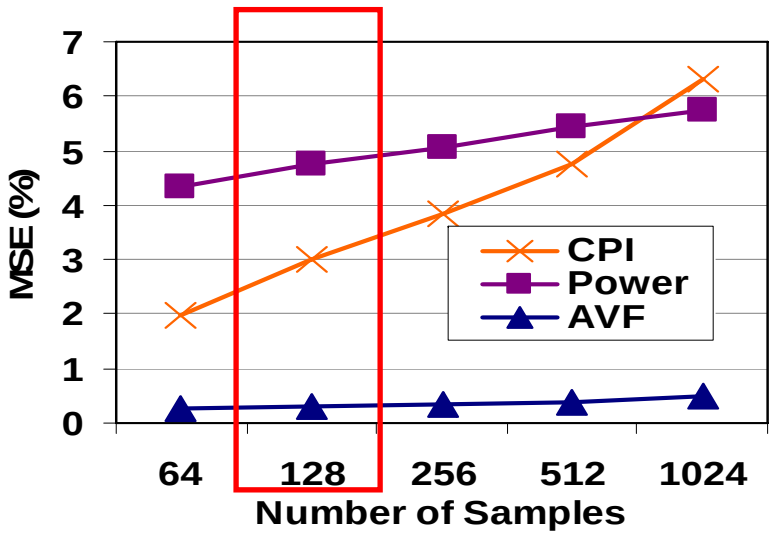
$$MSE = \frac{1}{N}\sum_{k=1}^{N}((x(k) - \hat{x}(k))^2$$



Evaluation : sensitivity analysis

- Number of wavelet coefficients
- Number of samples

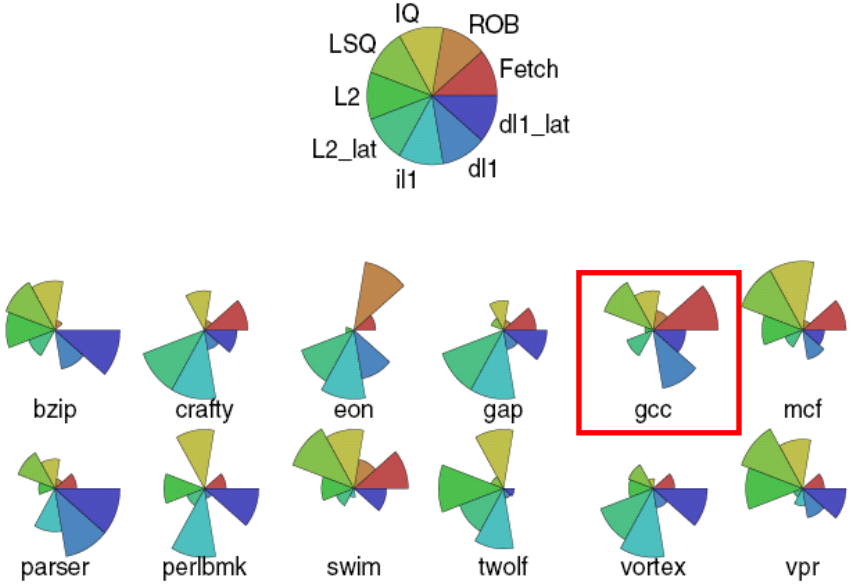




Evaluation : significance

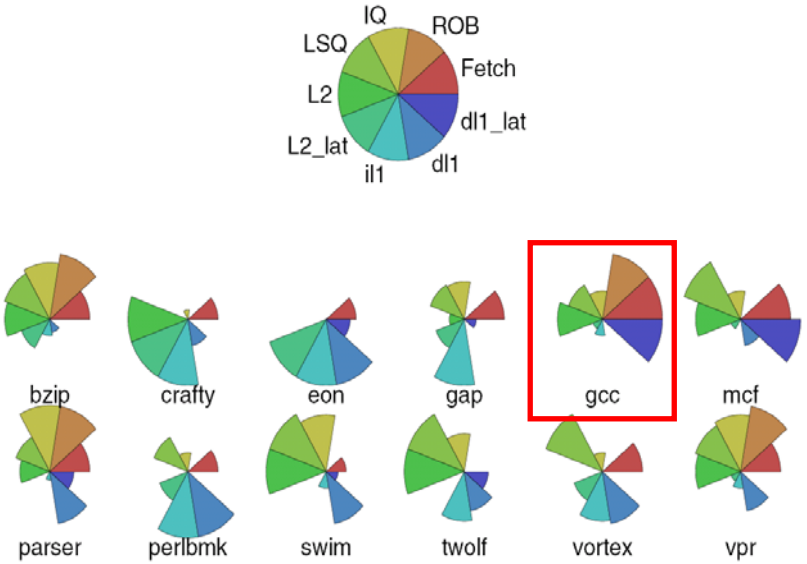
- Which parameters are dominant?
- Which observations show similar behavior?

(a) Performance (CPI)



Fetch, LSQ, Dl1

(b) Reliability (AVF)

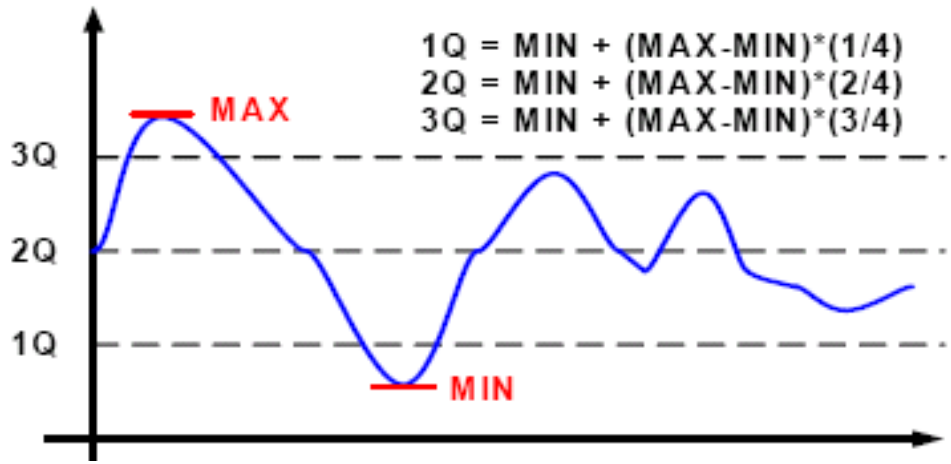


Fetch, ROB, Dl1_Lat

Case study – 1 (1/2)

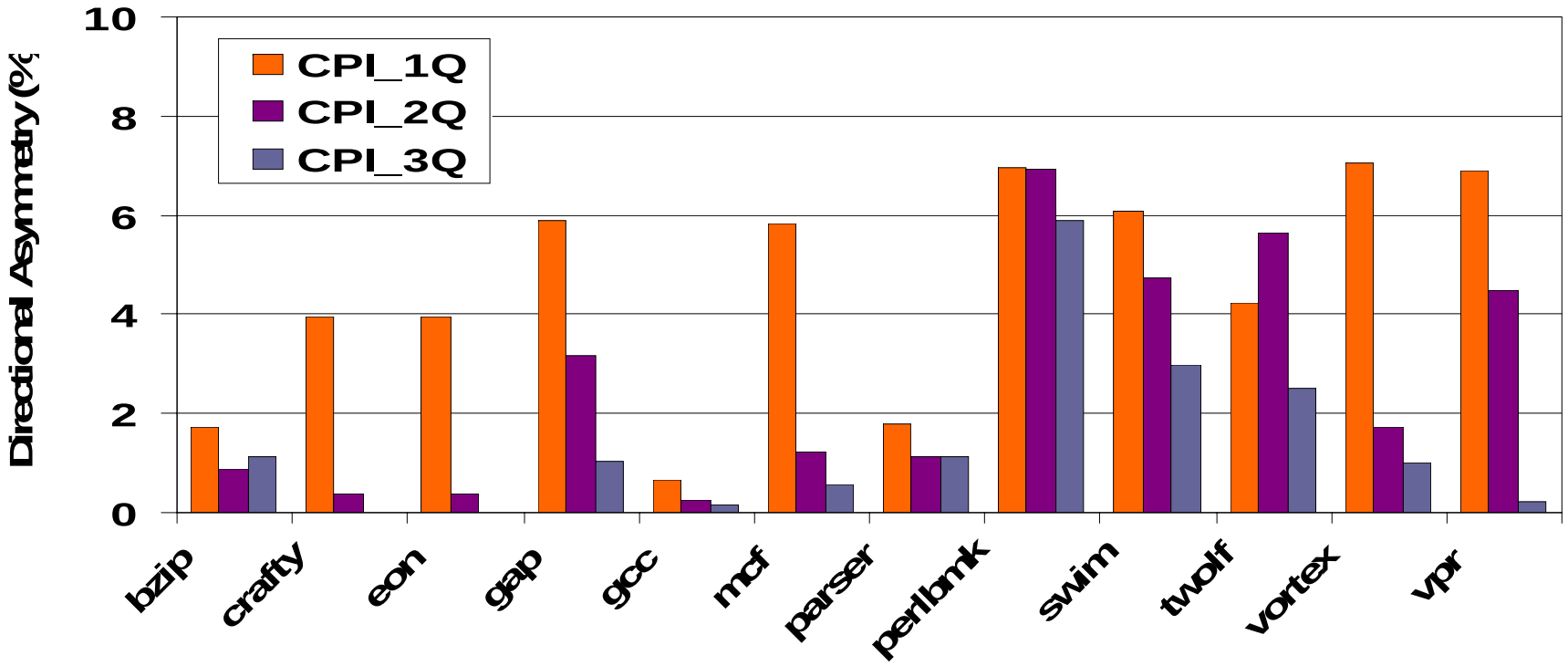
- Scenario-based prediction
  - Allows architect to quickly examine the application worst-case scenarios
- Directional Symmetry(DS) metric

$$DS = \frac{1}{N}\sum_{k=1}^{N}\varphi\left(x(k)\cdot\hat{x}(k)\right)$$



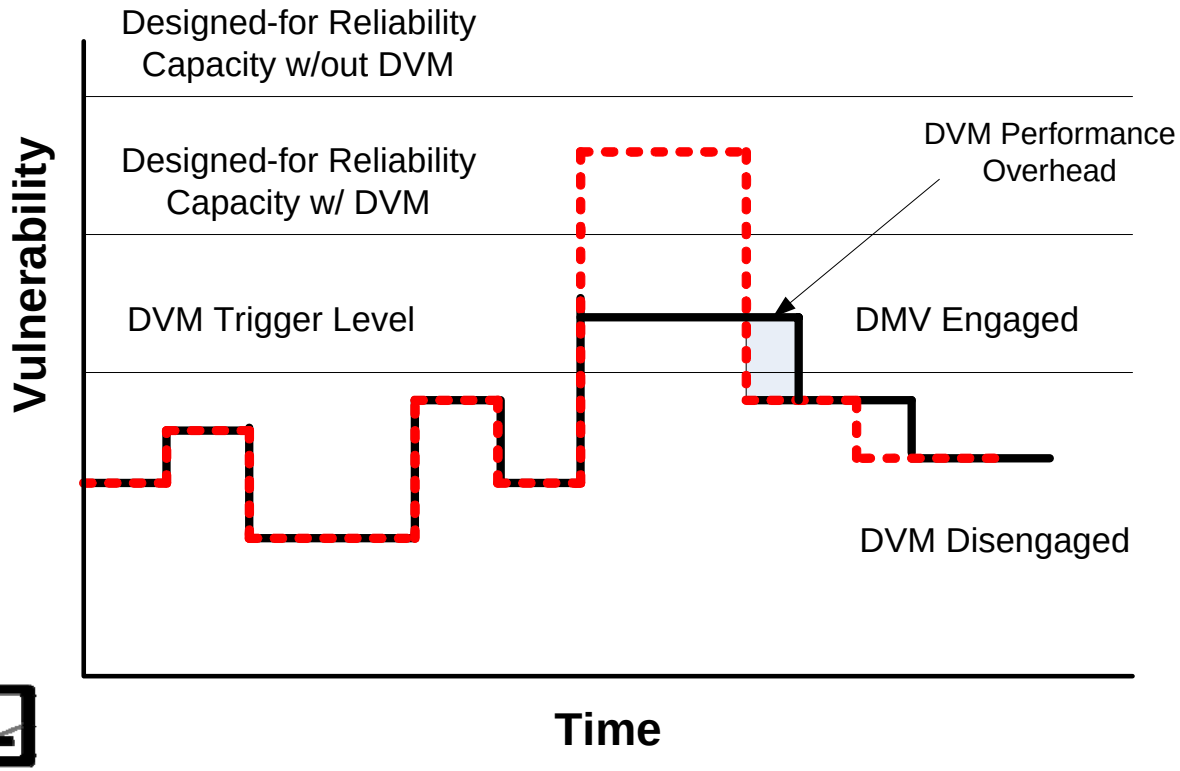
Case study – 1 (2/2)

- Directional Asymmetry (1-DS)



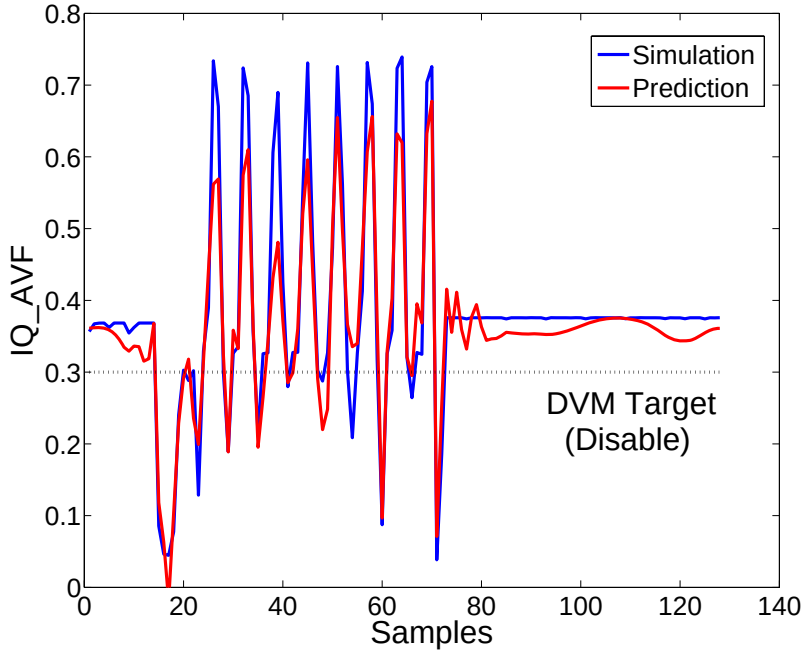
Case study – 2 (1/3)

- DVM(Dynamic Vulnerability Management)
  - A set of strategies to control hardware runtime soft-error susceptibility under a tolerable threshold

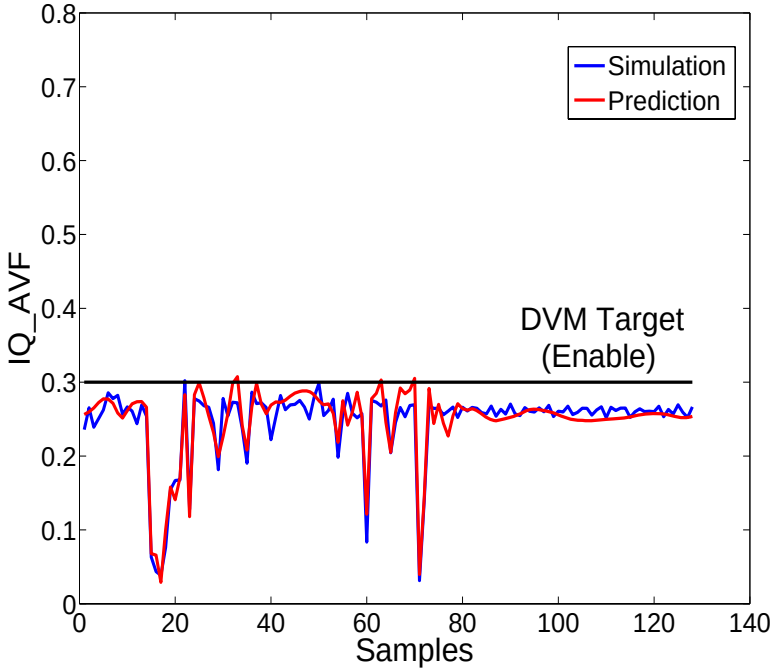


Case study – 2 (2/3)

(a) DVM_Disabled



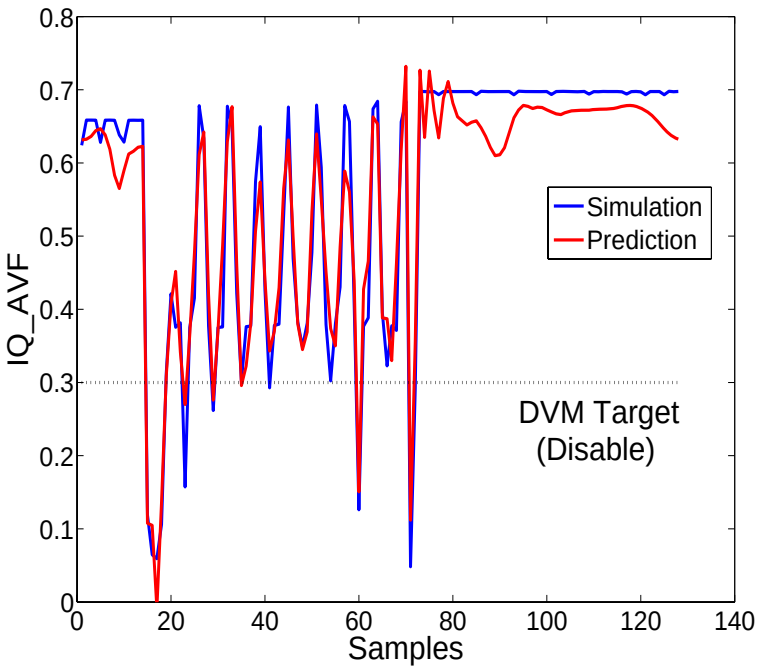
(b) DVM_Enabled



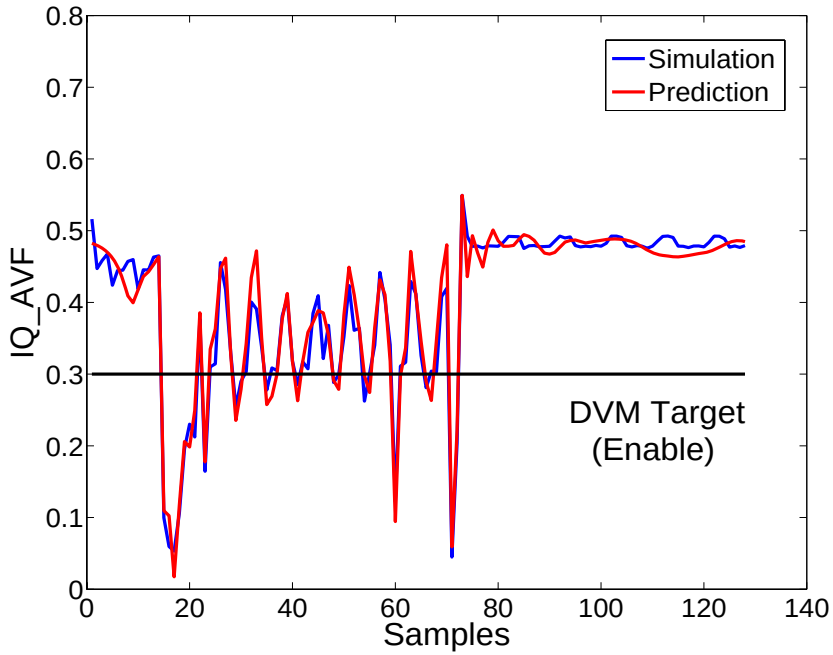
Configuration-A

Case study – 2 (3/3)

(a) DVM_Disabled



(b) DVM_Enabled



Configuration-B

Conclusions

- Propose accurate and informative prediction models
  - Wavelet based multiresolution decomposition
  - Neural network based non-linear regression modeling
- Predictive models achieve high accuracy in revealing workload dynamic behavior across a large microarchitecture design space
- The proposed techniques can be used to efficiently explore workload scenario-driven architecture optimizations

Questions

- Thank you for listening