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An Energy Characterization Framework for Software-Based Embedded Systems

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Outline

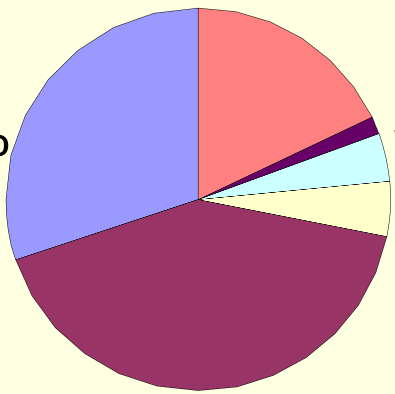
- Introduction
- Energy characterization framework
- Training bench generation
- Experimental results
- Summary

Back Ground (1/2)

Power consumption at a processor on embedded system has a big portion

Power Distribution in a PDA class sample device

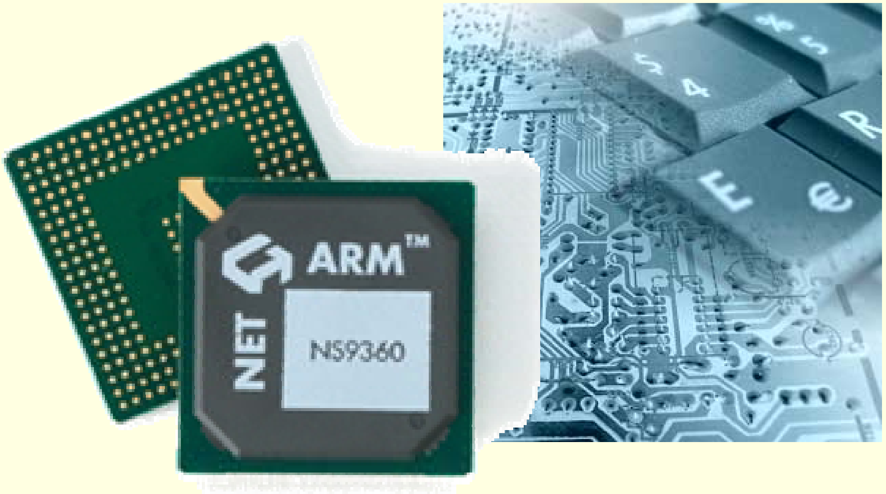
Cliff Brake, Accelent Systems, Inc. (May, 2003)



www.princeton.edu/~wolf/

Back Ground (2/2)

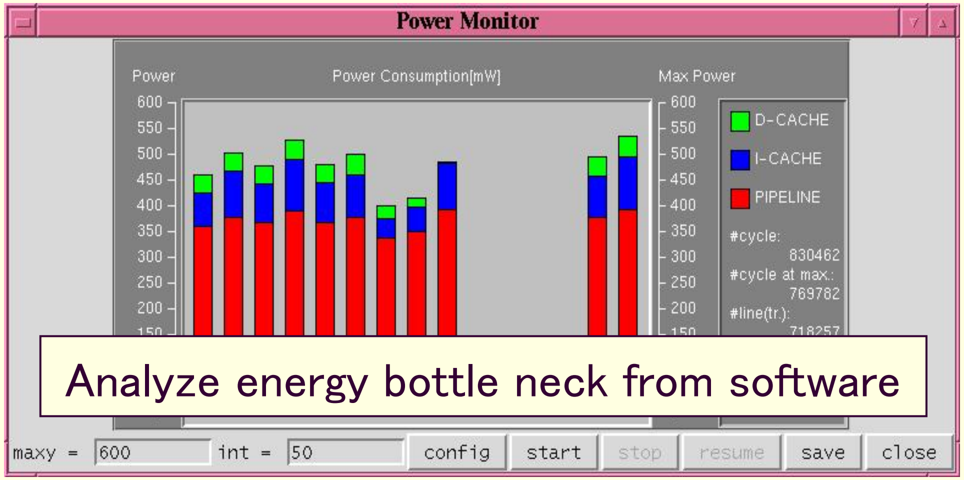
Power consumption at a processor depends on the software being executed

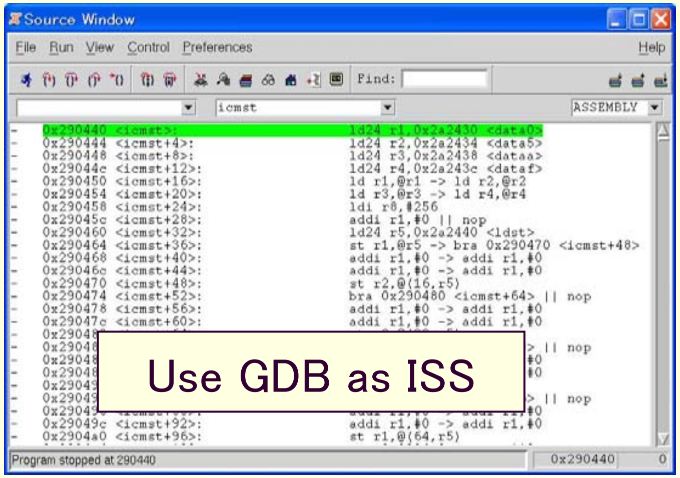


SW designer should think power dissipation by SW that he is developing

Energy Analysis Tool

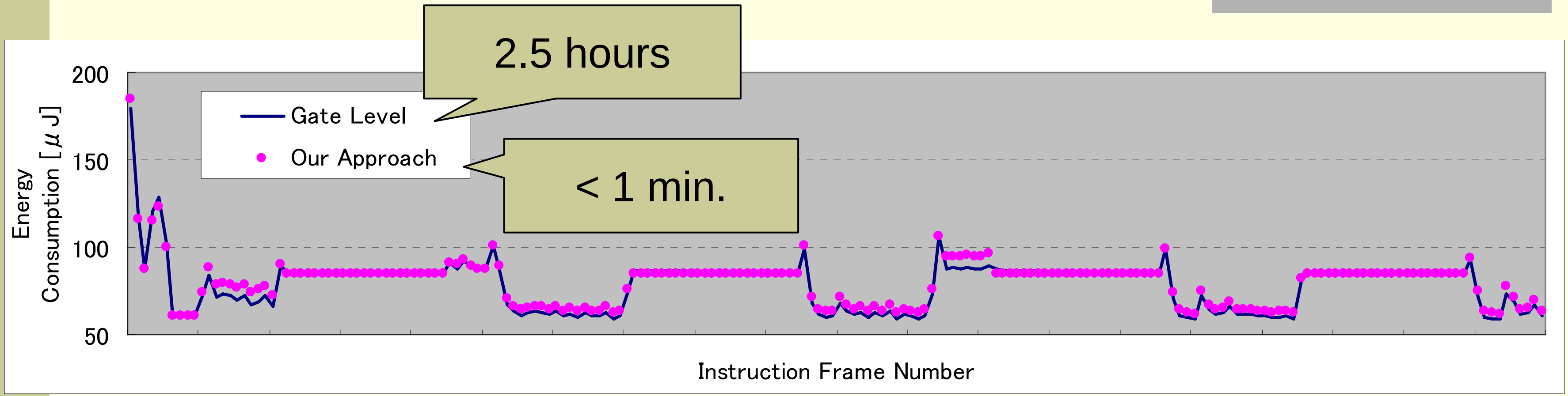
We propose a characterization technique to find a good energy model for a processor



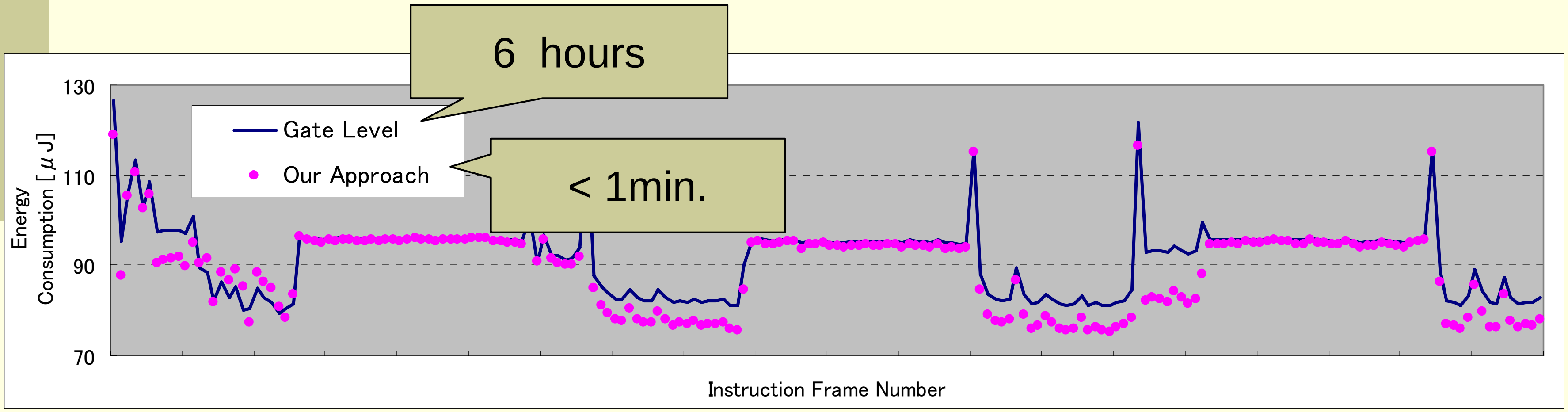


Fast, accurate, and processor-independent
Instruction level energy estimation

Experimental Result



Energy estimation for JPEG encoder executed on a M32R-II processor



Energy estimation for JPEG encoder executed on a SH3-DSP processor

Related Work (1/2)
High-level energy estimation

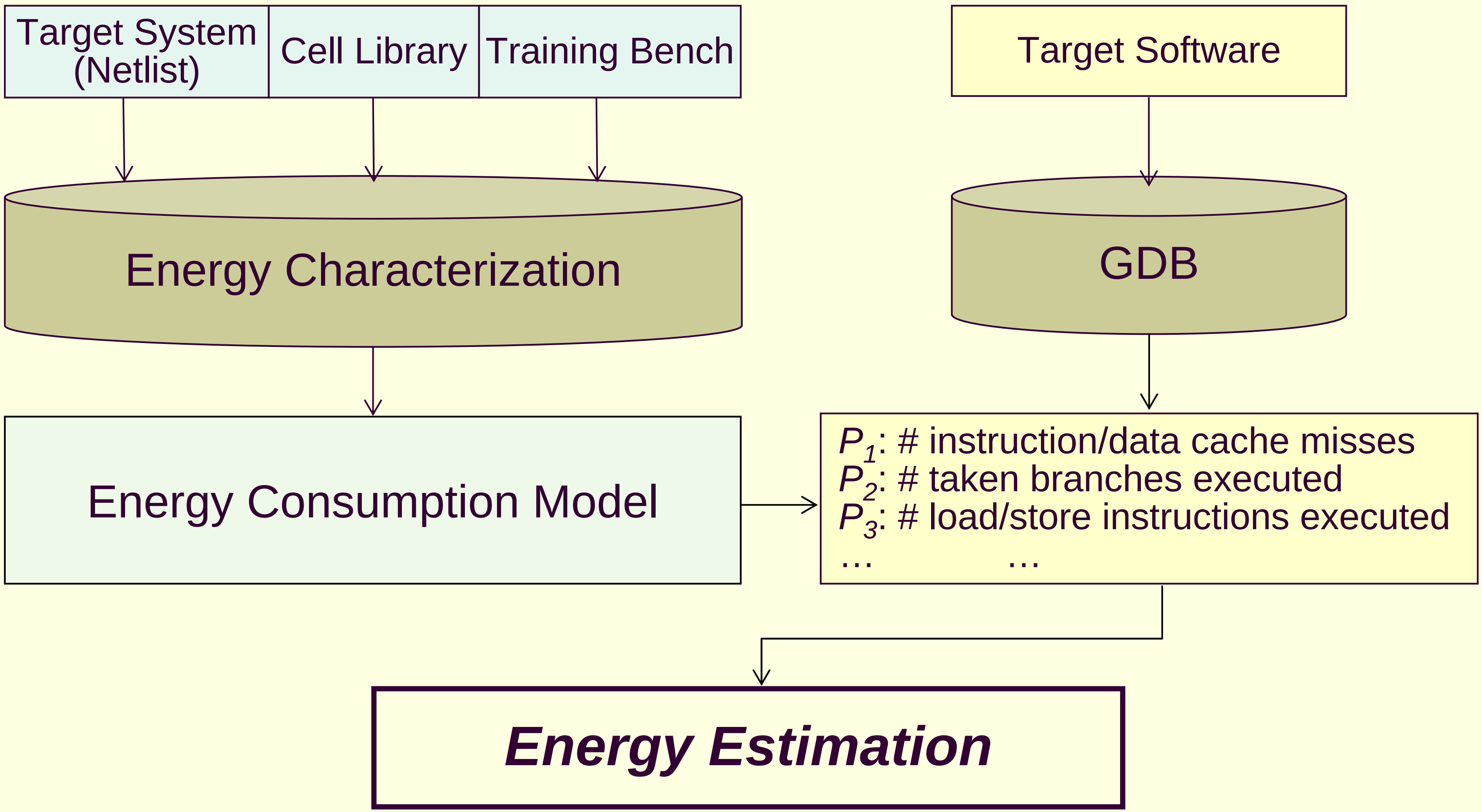
- Instruction-level modeling
  - Energy estimation by instruction-set simulator
  - Instruction level energy modeling by measuring the average power consumption of each instruction while executed in a loop

V. Tiwari, S. Malik, and A. Wolfe, "*Power analysis of embedded software: a first step towards software power minimization*," IEEE Tr. On VLSI, vol. 2, no. 4, pp. 437-445, Dec. 1994.

- Structural modeling of the underlying hardware architecture
  - Make power models by estimating capacitance on the circuit
  - Keep track of which units are accessed per cycle by cycle-level performance simulation

D. Brooks, V. Tiwari, and M. Matonosi, "*Wattch: A Framework for Architectural-Level Power Analysis and Optimization*," in Proc. Of ISCA, pp. 84-94, June. 2000.

Our Approach



Related Work (2/2)
Characterization-based energy estimation

- Characterization-based macro-modeling
  - Regression analysis to model software energy
  - Model the energy consumption using linear expression

$$E = \sum_{j=1}^{p} c_j P_j$$

- P_j : parameters of the model
- c_j : corresponding coefficients
- p : number of parameters

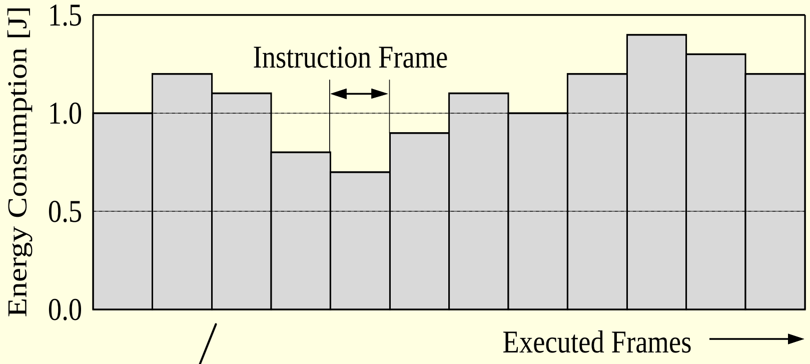
$$\mathrm{P} = \begin{pmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,p} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,p} \\ \cdots & \cdots & \cdots & \cdots \\ P_{n,1} & P_{n,2} & \cdots & P_{n,p} \end{pmatrix} \qquad \mathrm{E} = \begin{pmatrix} E_1 \\ E_2 \\ \cdots \\ E_n \end{pmatrix} \Rightarrow C = \begin{pmatrix} c_1 \\ c_2 \\ \cdots \\ c_n \end{pmatrix} = \left[\mathrm{P}^T \mathrm{P}\right]^{-1} \mathrm{P}^T \mathrm{E}$$

Evaluate set of parameters	Obtain the energy consumption by low-level estimator	Obtain coefficient using regression analysis

T. K. Tan, A. Raghunathan, G. Lakshminarayana, and N. K. Jha, "*High-level software energy macro-modeling*," in Proc. Design Automation Conf., 2001, pp. 605--610.

Overview of Energy Characterization

- Energy consumption model based on linear expression
- Evaluate energy from each divided instruction frames



Extract by instruction-set simulation

Estimate energy at gate level

Instruction frame 1 ⇨ $E_1 \longleftarrow E'_1 = c_1 P_{11} + c_2 P_{12} + c_3 P_{13} \cdots$

Instruction frame 2 ⇨ $E_2 \longleftarrow E'_2 = c_1 P_{21} + c_2 P_{22} + c_3 P_{23} \cdots$

…

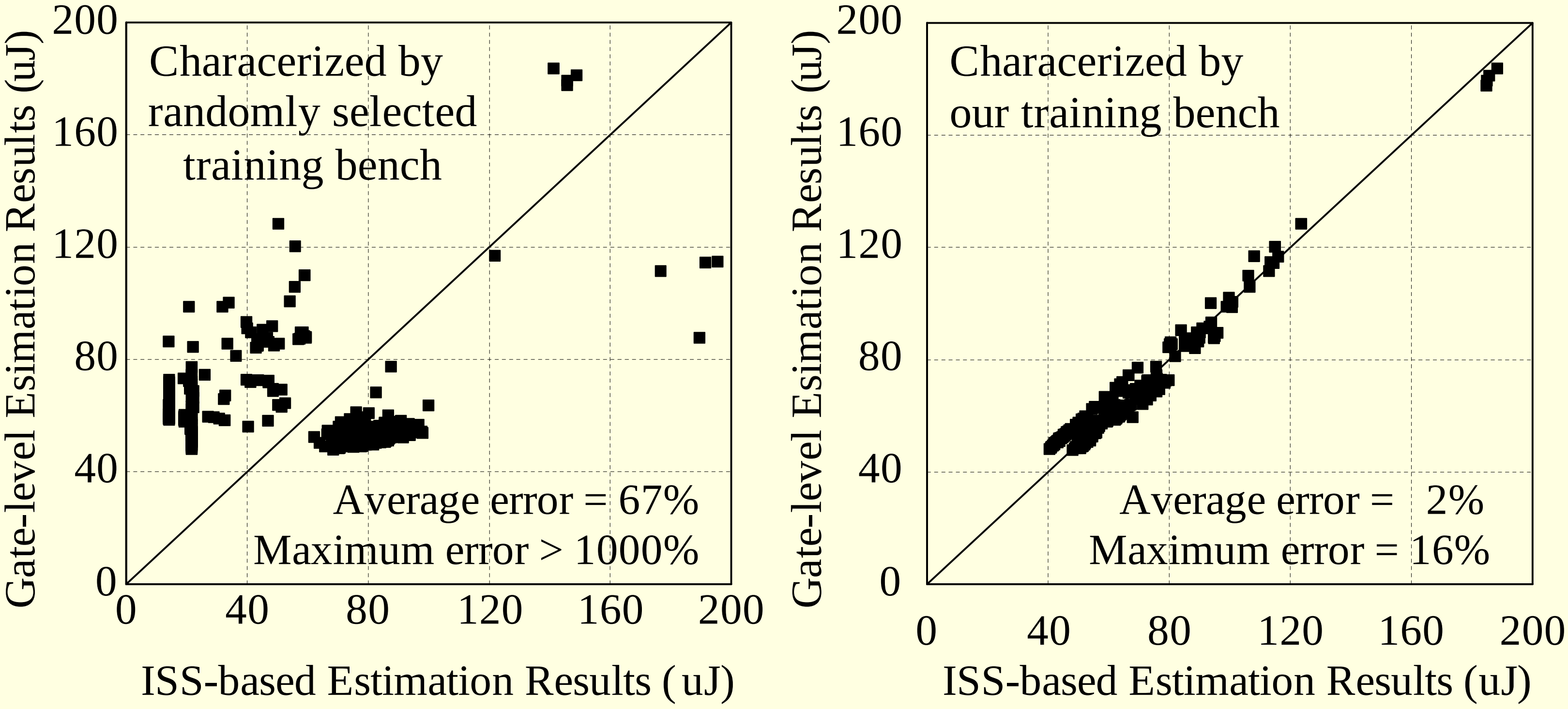
Instruction frame n ⇨ $E_n \longleftarrow E'_n = c_1 P_{n1} + c_2 P_{n2} + c_3 P_{n3} \cdots$

Solve the set of c_i which minimizes $\sum_{i=1}^{n} | E'_i - E_i |$

Error Sources of this characterization

- Parameter set selection
- Non-linear effects
- Training bench
- …

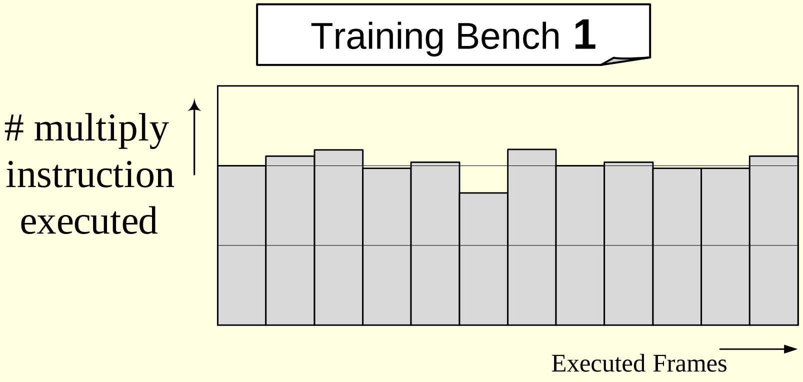
Motivational Example



Training bench dominates model accuracy !!

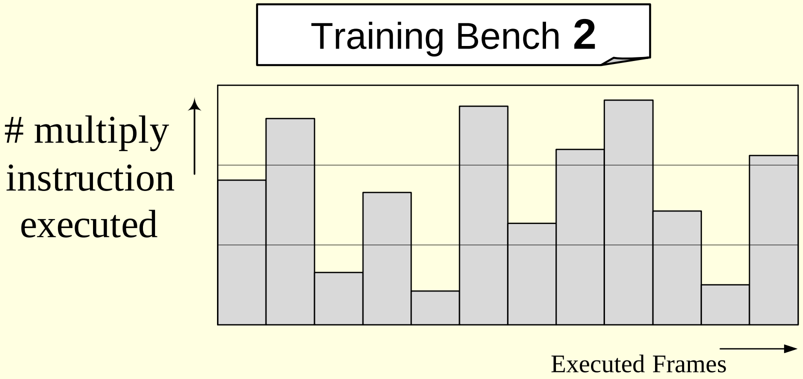
What is expected for a ‘good’ training bench ?

Criteria on Training Bench (1/2)



If parameter value of each frames is constant or mono-tone

Difficult to derive energy consumed by parameter



If parameter value of each frames is randomized

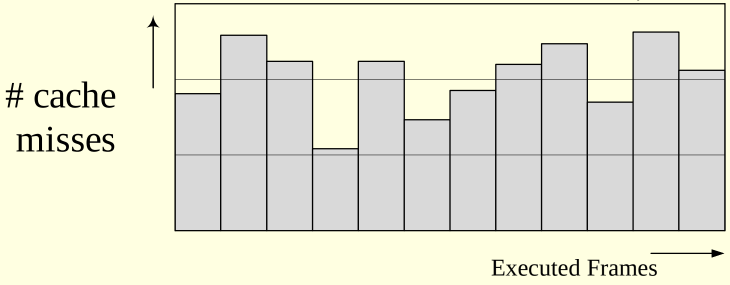
Suitable to derive energy consumed by parameter

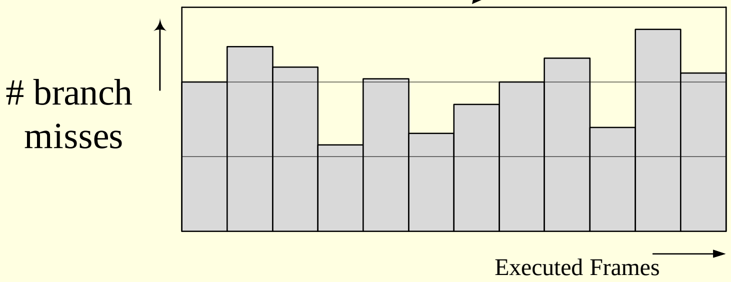
Criterion 1

Standard deviation of parameter value

Criteria on Training Bench (2/2)

$$E = c_1 P_1 + \ldots + c_{cache\_miss} \boxed{P_{cache\_miss}} + c_{branch\_miss} \boxed{P_{branch\_miss}}$$





If correlation is strong between two parameters

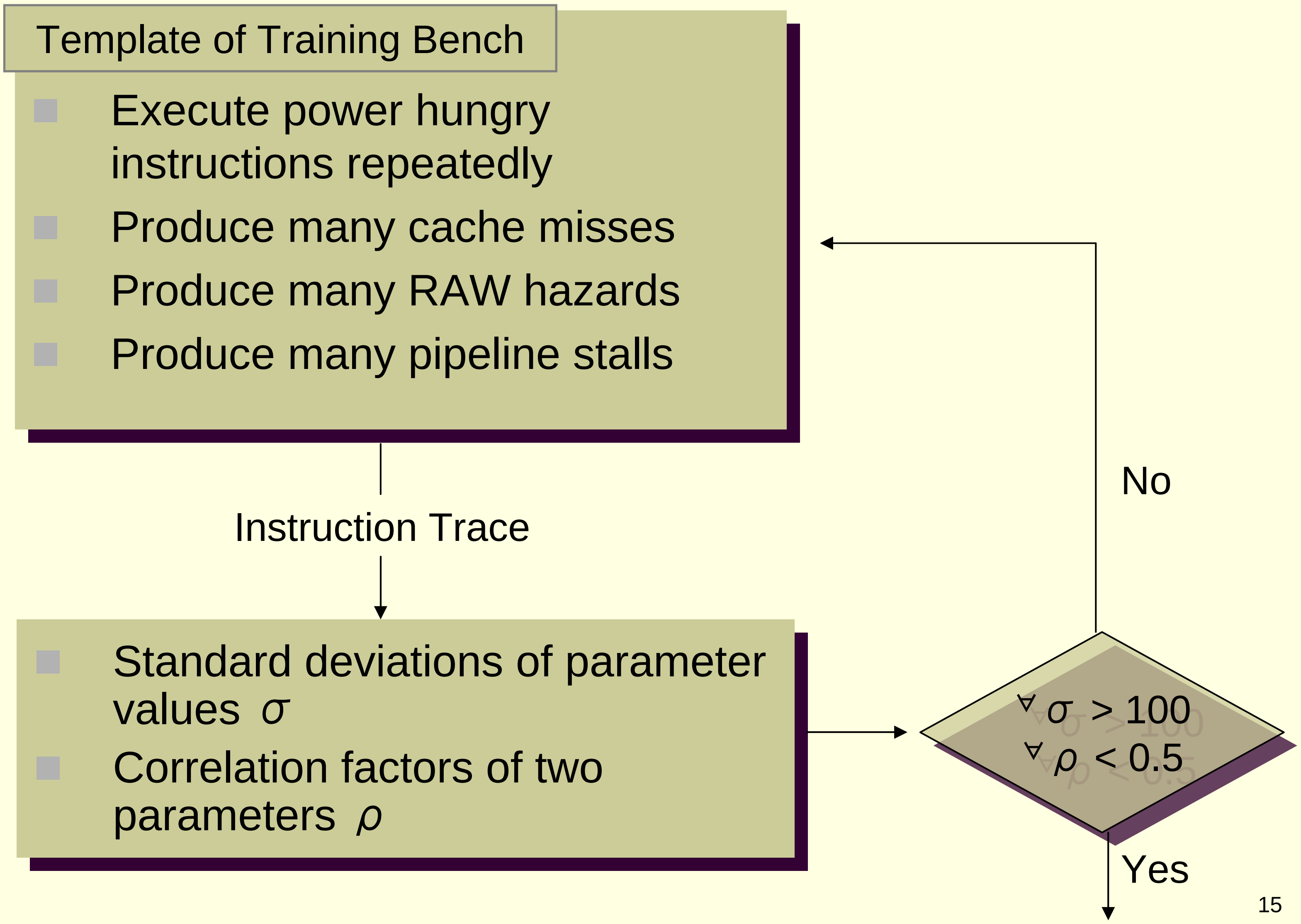
⇓

Difficult to derive energy consumption by each parameters

Criterion 2

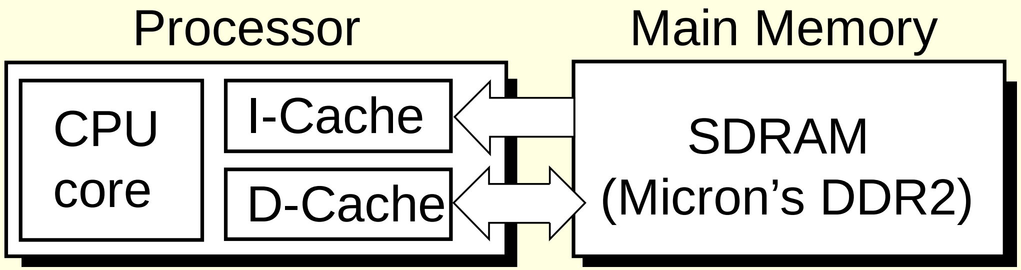
Correlation between parameters

Training Bench Generation



Experiment

- Target system



  - Processors
    - M32R-II, SH3-DSP
  - 0.18 μ m CMOS library

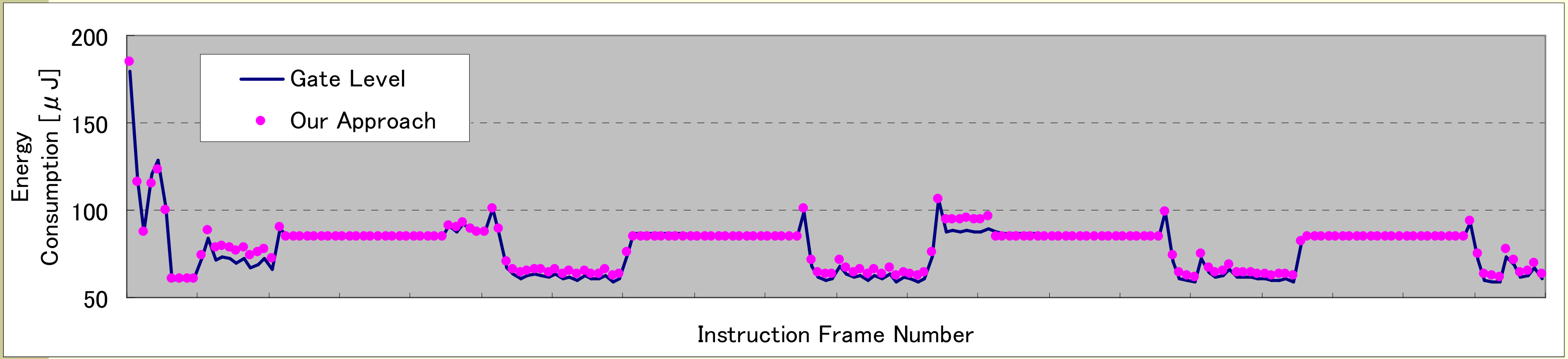
Experimental Result - Energy estimation error

	M32R-II		SH3-DSP	
	Average Error	Maximum Error	Average Error	Maximum Error
JPEG	2.70 %	10.32 %	3.17 %	11.89 %
JPEG_O	6.09 %	16.46 %	6.33 %	10.02 %
MPEG2	1.54 %	3.97 %	1.32 %	3.41 %
MPEG2_O	1.78 %	5.15 %	1.31 %	5.63 %
compress	5.00 %	6.41 %	5.73 %	10.84 %
compress_O	4.35 %	7.18 %	1.73 %	15.15 %
FFT	1.55 %	6.87 %	1.27 %	3.26 %
FFT_O	1.45 %	5.59 %	1.15 %	4.75 %
DCT	1.42 %	8.58 %	1.12 %	2.20 %
DCT_O	1.47 %	8.07 %	1.51 %	3.04 %
Total	**2.74 %**	**16.46 %**	**2.47 %**	**15.15 %**

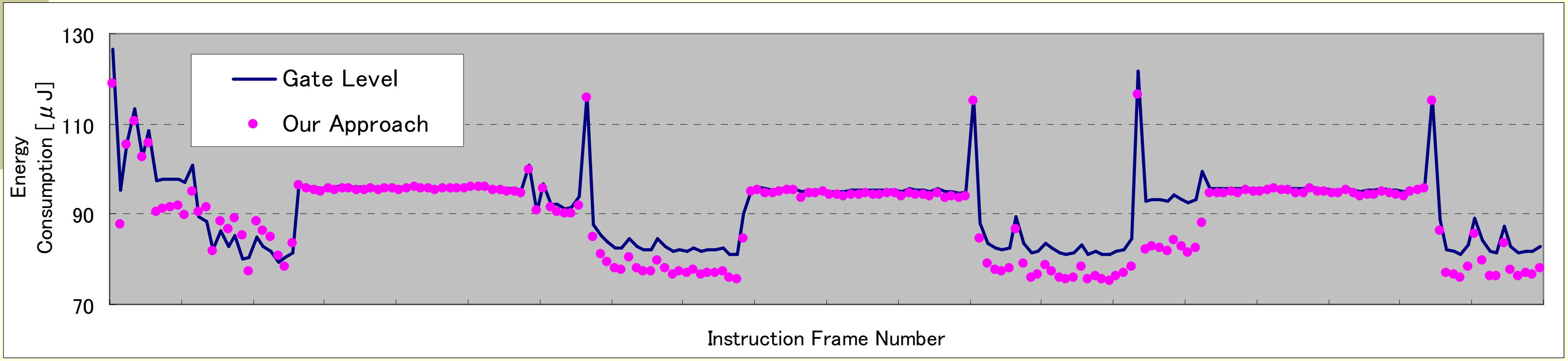
Compared to the gate level estimation

*_O : compiled with a "-O3" optimize option

Experimental Result



Energy estimation for JPEG encoder executed on a M32R-II processor



Energy estimation for JPEG encoder executed on a SH3-DSP processor

Summary

- Proposed energy characterization framework for processor-based embedded system
- Error is on an average 3% and worst case 16%

- Future work
  - Compare result to board level measurement
  - Extend current work to multi-core processor systems
  - Extend to systems running on RTOS

Thank You !