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1. INTRODUCTION

2. RELATED WORK

3. MODEL OVERVIEW

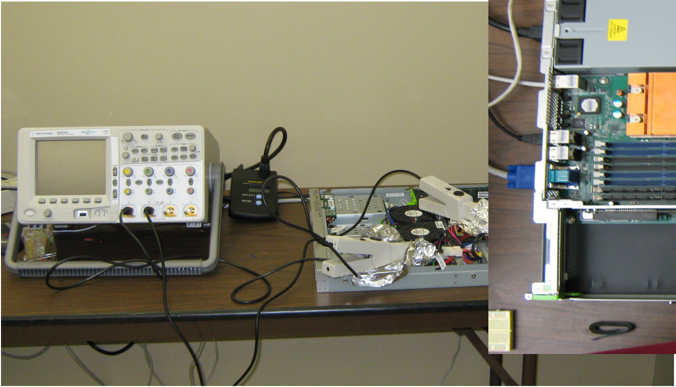

Fig. 1. System Under Test.

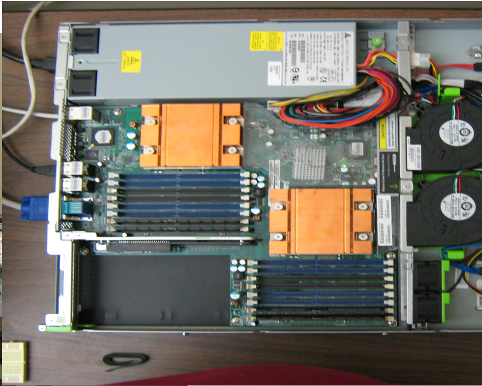

Fig. 2. Detailed View of the System Under Test.

3.1 Hardware Environment

Table I. Test Hardware Configuration

	Sun Fire 2200
CPU	2 AMD Opteron
CPU L2 cache	2x2MB
Memory	8GB
Internal disk	2060GB
Network Interface Card	2x1000Mbps
Video	On-board
Height	1 rack unit

3.2 Software Environment

4. THE STRUCTURE OF THE MODEL

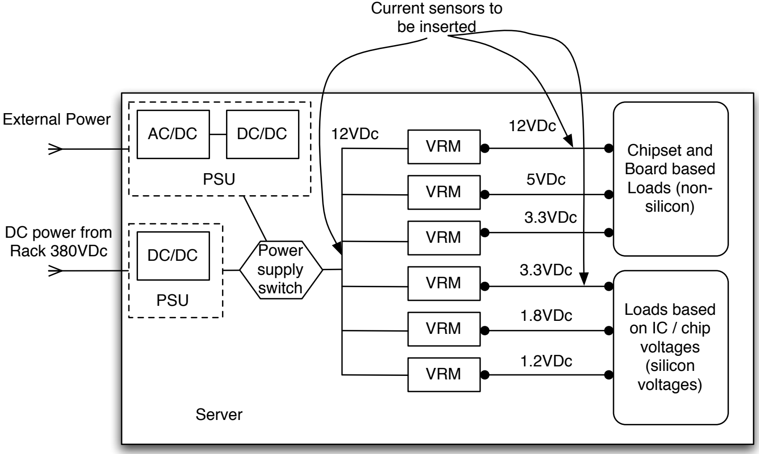

Fig. 3. Power distribution model for the server blade

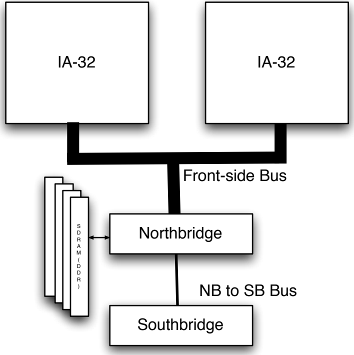

Fig. 4. Intel Core Server Architecture

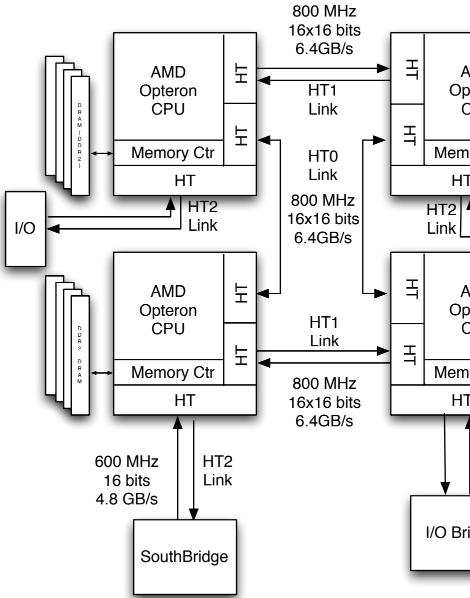

Fig. 5. AMD Opteron Server Architecture

P_R

$v_k(t)$

$i_k(t)$

$$p_k(t) = v_k(t) \cdot i_k(t)$$

M

$$p_{v1}(t) = \sum_{k=0}^{M} v_k(t) \cdot i_k(t) \tag{1}$$

N

$$p_{dc}(t) = \sum_{j=0}^{N} p_{vj}(t) = \sum_{j=0}^{N} \sum_{k=0}^{Mj} v_k(t) \cdot i_k(t) \tag{2}$$

t_2

t_1

$$E_{dc} = \int_{t_1}^{t_2} p_{dc}(t)dt = \int_{t_1}^{t_2} \sum_{j=0}^{N} p_{vj}(t)dt = \int_{t_1}^{t_2} \sum_{j=0}^{N} \sum_{k=0}^{Mj} v_k(t) \cdot i_k(t)dt \tag{3}$$

$$
\begin{aligned}
E_{dclv} &= \int_{t_1}^{t_2} p_{dclv}(t)dt \\
&= \int_{t_1}^{t_2} (\sum_{k=0}^{M1} v_k(t) \cdot i_k(t) + \sum_{k=0}^{M2} v_k(t) \cdot i_k(t))dt \\
&\leq 0.2P_R
\end{aligned} \tag{4}
$$

$M1$

$M2$

$$E_{dc} = E_{system}$$

E_{proc}

$$E_{memory}$$

E_{em}

E_{board}

$$E_{hdd}$$

4.1 Processor energy consumption

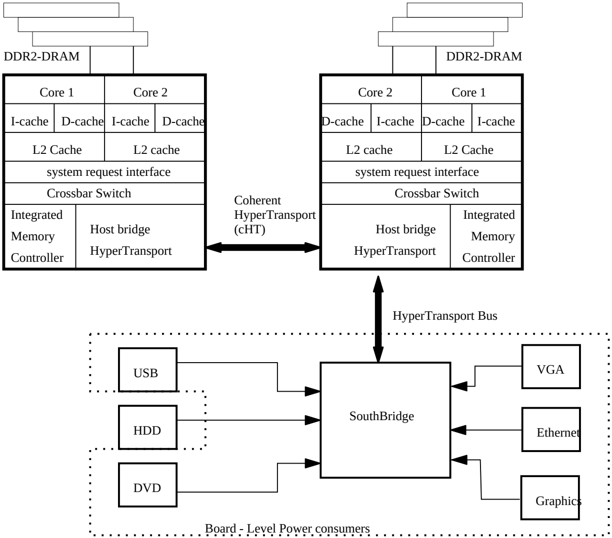

Fig. 6. Dual-core AMD Opteron based server architecture.

$$\mathbf{P_{proc}} = \mathbf{H} \cdot \mathbf{X} = [\beta_0 \cdots \beta_{10}]^{\mathbf{T}} \cdot [\mathbf{Var_0} \cdots \mathbf{Var_{10}}]^{\mathbf{T}}$$

X

4.2 DRAM energy

4.3 Hard disk energy

Table II. HItachi HDT725025VLA360 disk power parameters

Parameter	Value
Interface	Serial ATA
Capacity	250 GB
Rotational speed	7200 rpm
Power (spin up)	5.25 W (max)
Power (Random read, write)	9.4 W (typical)
Power (Silent read, write)	7 W (typical)
Power (idle)	5 W (typical)
Power (low RPM idle)	2.3 W (typical for 4500 RPM)
Power (standby)	0.8 W (typical)
Power (sleep)	0.6 W (typical)

E_{hdd}

$$E_{hdd} = P_{spin-up} \times T_{su} + P_{read} \sum N_r \times T_r + P_{write} \sum N_w \times T_w + \sum P_{idle} \times T_{id}$$

$$P_{spin-up}$$

T_{su}

$$T_{su}$$

P_{read}

N_r

T_r

$$P_{read}$$

$13.3 \mu W$

$6.67 \mu W$

N_r

N_w

$$E_{hdd}$$

$$E_{hdd} = \int_{t1}^{t2} \left\{ v_1(t) \times i_1(t) + v_2(t) \times i_2(t) \right\} dt \tag{5}$$

4.4 Board Components

E_{board}

$$E_{board} = \left(\sum V_{power-line} \times I_{power-line}\right) \times t_{time-slice} \tag{6}$$

4.5 Electromechanical Energy

$$E_{elect}$$

$$E_{elect}$$

$$P_{fan} = P_{base} \cdot \left(\frac{RPM_{fan}}{RPM_{base}} \right)^3 \tag{7}$$

$$P_{base}$$

$$P_{elect} = V(t) \cdot I(t) + \sum_{i=1}^{N} P_i \tag{8}$$

N

P_i

$i-th$

$$\eta = \frac{V(t) \cdot I(t)}{P_{in}} \tag{9}$$

η

T_p

$$E_{elect} = \int_0^{T_p} [V(t) \cdot I(t) + \sum_{i=1}^{N} P_i] \, dt \tag{10}$$

4.6 Combined Model

$$E_{system} = \alpha_0(E_{proc} + E_{mem}) + \alpha_1 E_{em} + \alpha_2 E_{board} + \alpha_3 E_{hdd}$$

α_0

α_1

α_2

α_3

Table III. SPEC CPU2006 Benchmarks Used in Callibration

Benchmark		Type	Use
perlbench	C	Integer	PERL Programming Language
bzip2	C	Integer	Compression
mcf	C	Integer	Combinatorial Optimization
omnetpp	C++	Integer	Discrete Event Simulation
gromacs	C/Fortran	Floating Point	Biochemistry/Molecular Dynamics
cacstusADM	C/Fortran	Floating Point	Physics/General RElativity
leslie3d	Fortran	Floating Point	Fluid Dynamics
lbm	C	Floating Point	Fluid Dynamics

5. APPLICATION OF MODEL TO PHYSICAL SYSTEM

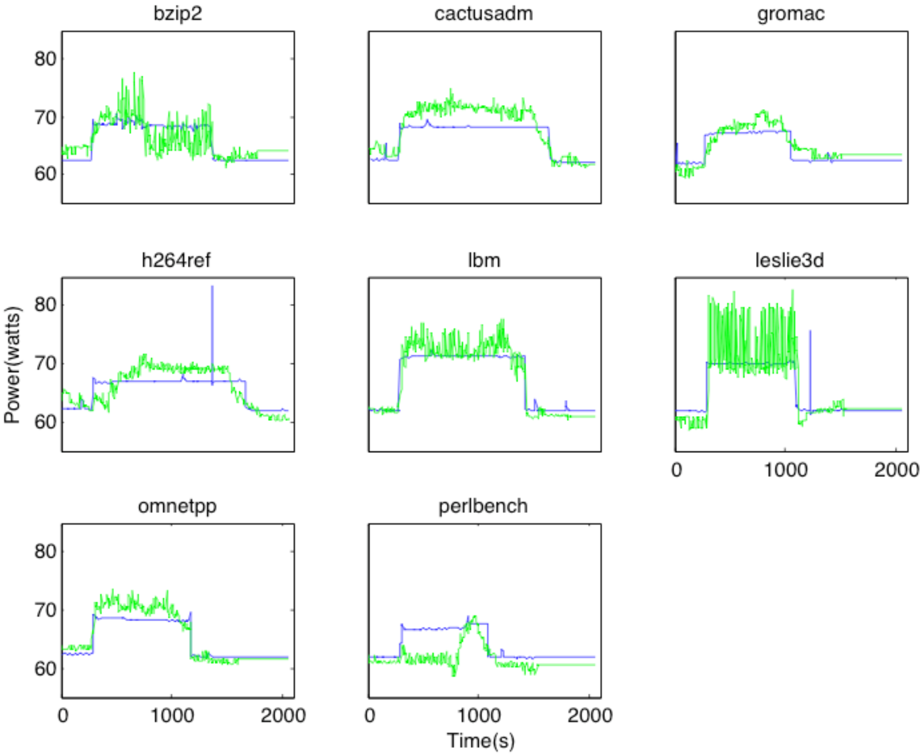

Fig. 7. Actual energy vs. predicted (geometric mean)

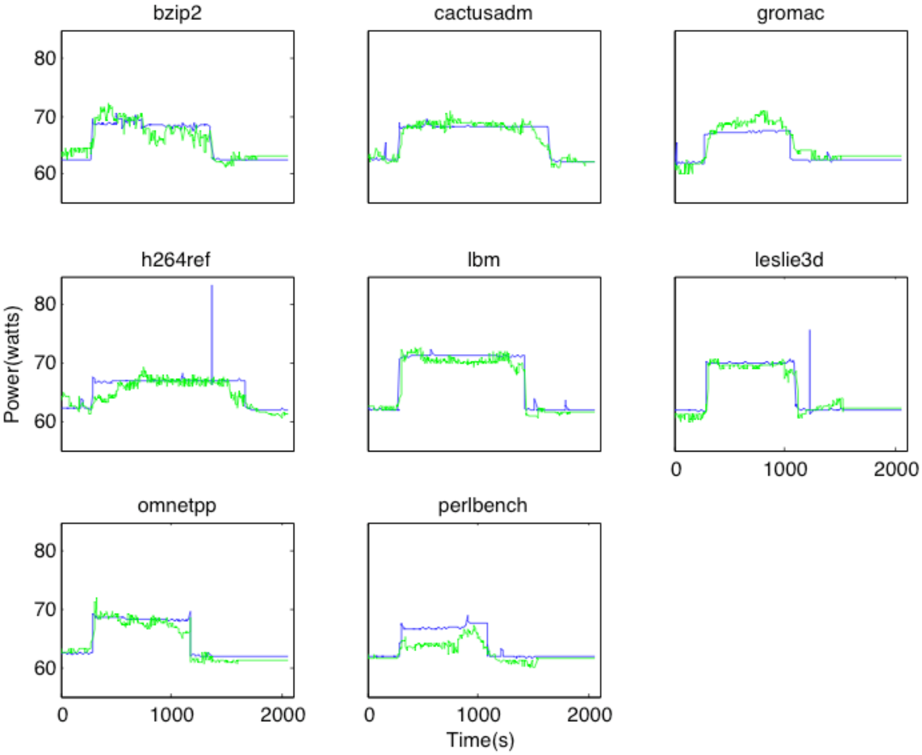

Fig. 8. Actual energy vs. predicted (arithmetic mean)

Table IV. Overall Regression Model.

	Coeff.	Variable
β_0	32.707822	
β_1	1.310433	Ambient Temp0
β_2	0.541550	Ambient Temp1
β_3	0.538486	CPU0 Die Temp
β_4	0.609868	CPU1 Die Temp
β_5	0.007385	HT1 Bus X-Actions
β_6	0.00372	HT2 Bus X-Actions
β_7	0.003274	L1/L2 Cache Miss for Core0
β_8	0.003371	L1/L2 Cache Miss for Core1
β_9	0.003200	L1/L2 Cache Miss for Core2
β_{10}	0.003229	L1/L2 Cache Miss for Core3
β_{11}		Disk bytes read
β_{12}		Disk bytes written

Table V. ANOVA for Consoldated Model

Source	df	SS	MS	F	P
Regr	10.00	2261.17	226.12	1150.23	0.00
Resid	399.00	78.44	0.1966		
Total	409.00	2339.60			
R-sq	0.97	Adj. R-sq	0.97		

6. EVALUATION

Table VI. Model error for each benchmark

Benchmark	Mean	Median	Std	Var	PercentErr
bzip2	2.045467	1.905644	1.588513	2.523374	0.031211
cactusadm	2.202807	2.404386	1.319229	1.740365	0.033307
gromac	1.366119	1.144044	0.800663	0.641062	0.021318
h264ref	1.853035	1.784534	1.197386	1.433734	0.028322
lbm	1.354063	0.836553	1.316524	1.733235	0.020198
leslie3d	2.031854	0.770795	3.117056	9.716037	0.031152
omnetpp	1.371142	1.011408	1.045460	1.092987	0.021164
perlbench	2.290307	1.266262	1.949692	3.801300	0.035888

β

Table VII. Model error for a model built from only Integer benchmarks

Benchmark	Mean	Median	Std	Var	PercentErr
bzip2.csv	2.404394	2.344587	0.951873	0.906063	0.036688
cactusadm.csv	2.017294	1.378231	1.611999	2.598541	0.030502
gromac.csv	2.714051	2.071705	1.489210	2.217745	0.042352
h264ref.csv	3.122320	3.133434	1.284671	1.650381	0.047722
lbm.csv	2.934198	2.897681	1.509793	2.279475	0.043768
leslie3d.csv	2.125868	2.656877	1.596151	2.547697	0.032594
omnetpp.csv	2.626621	2.197175	1.812433	3.284913	0.040543
perlbench.csv	4.377417	4.549748	1.317535	1.735899	0.068591

Table VIII. Model error for a model built from only floating point benchmarks

Benchmark	Mean	Median	Std	Var	PercentErr
bzip2.csv	4.116983	2.556239	3.337882	11.141456	0.062820
cactusadm.csv	2.200758	2.512796	1.293131	1.672188	0.033276
gromac.csv	1.295837	1.512570	0.788880	0.622332	0.020221
h264ref.csv	0.910024	0.627757	1.129458	1.275676	0.013909
lbm.csv	3.205635	3.039159	2.850467	8.125159	0.047817
leslie3d.csv	6.329131	1.039084	6.862192	47.089677	0.097038
omnetpp.csv	2.138748	1.803460	1.924503	3.703713	0.033013
perlbench.csv	1.258867	1.202875	0.684415	0.468424	0.019726

6.1 Choice of Benchmarks

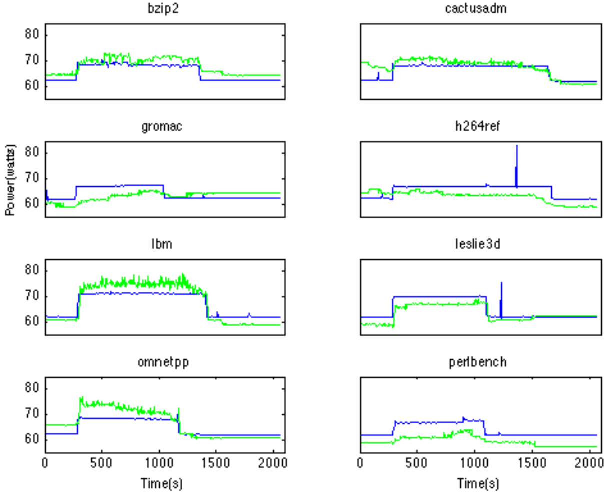

Fig. 9. Actual energy vs. predicted (Integer-only model)

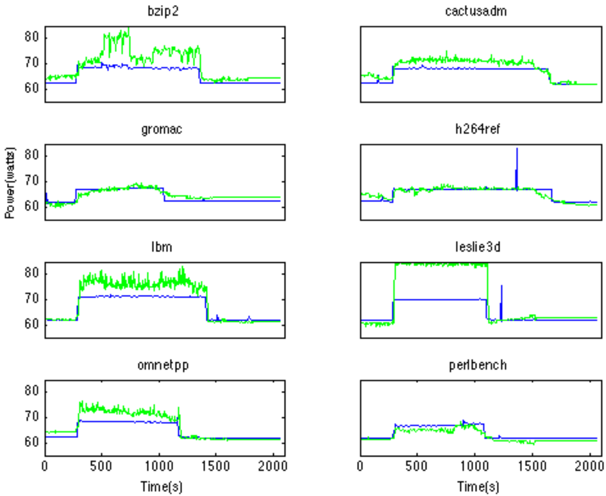

Fig. 10. Actual energy vs. predicted (FP-only model)

6.2 Measurement Tools

6.3 Processor Platform

β

7. CONCLUSIONS AND FUTURE WORK