Run-time Energy Consumption Estimation Based on Workload in Server Systems

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What does this picture tell us?

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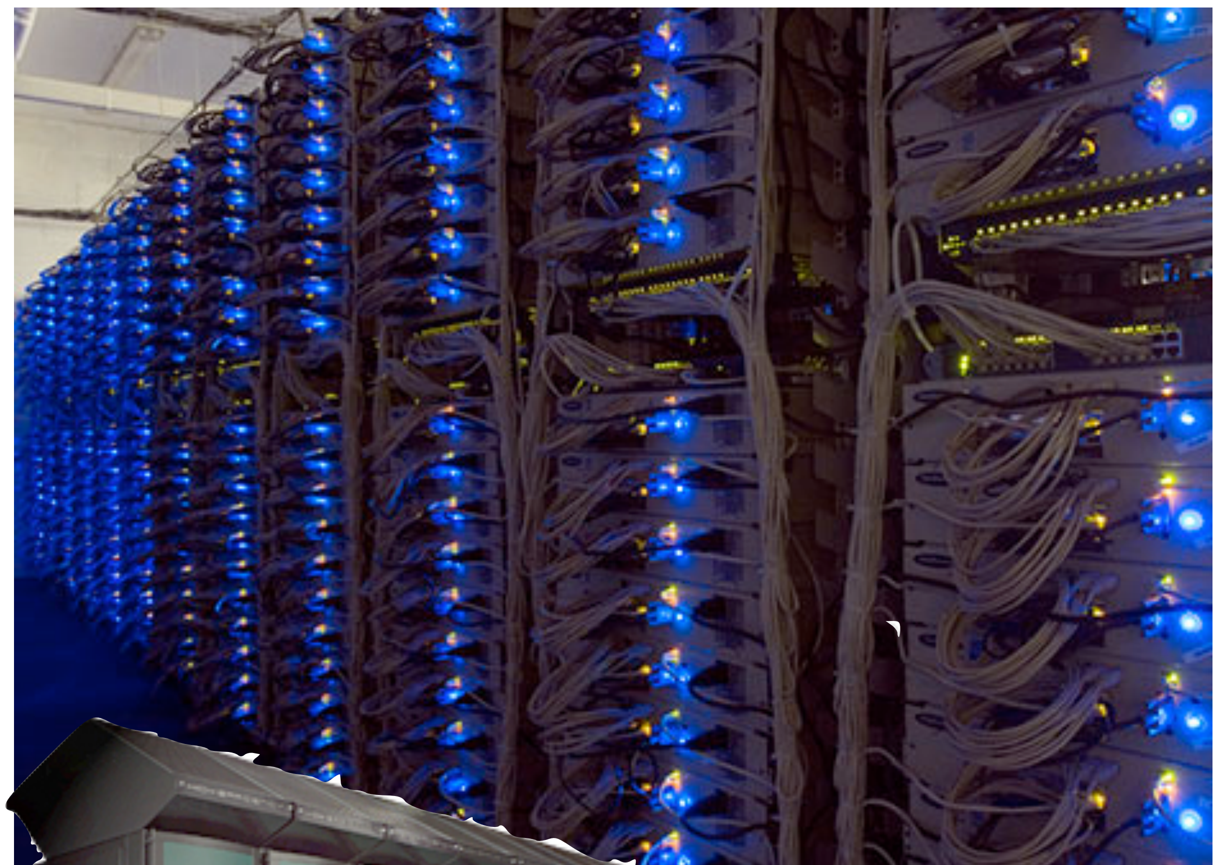
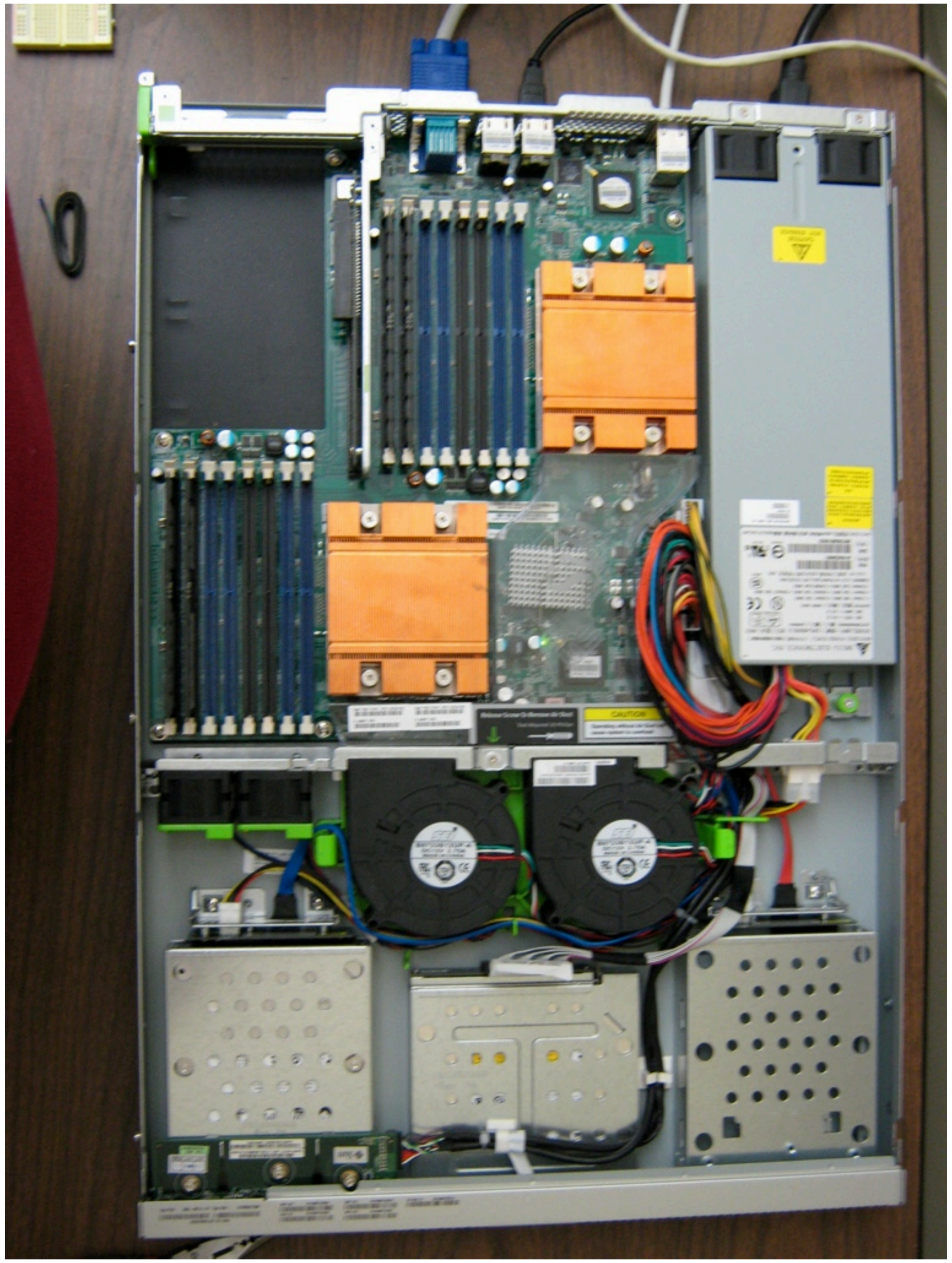
Introduction



- Server workloads?
  - –Laptop/desktop techniques?
  - –Full system model
    - interactions between processor, memory, storage
  - –Linkage between power, temperature, and energy

Model: Characteristics

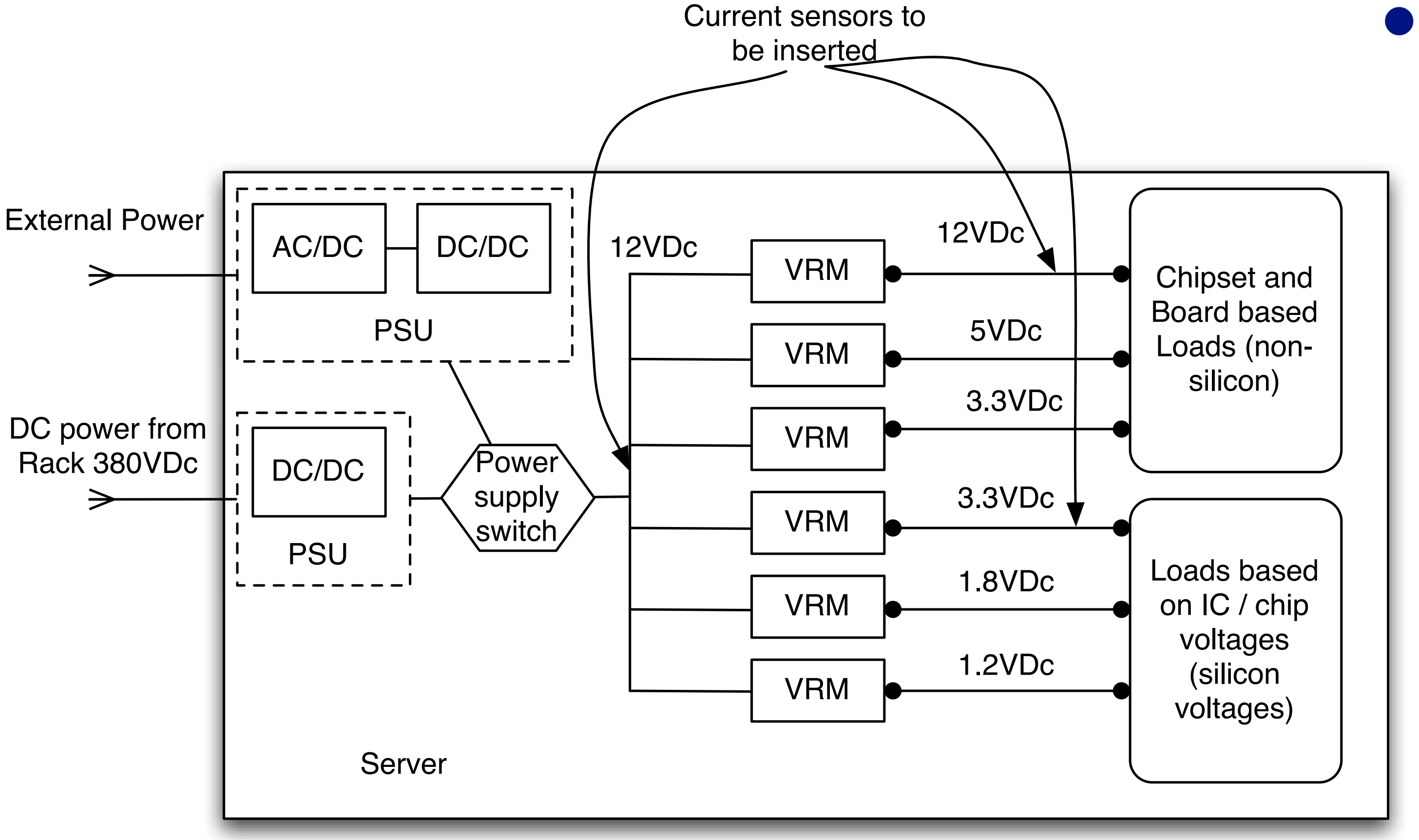


- Need a model that
  - Dynamically tracks DC power draw into system
  - We can use to control the power and thermal envelope of the system
    - based on the processing load

Model: Inputs

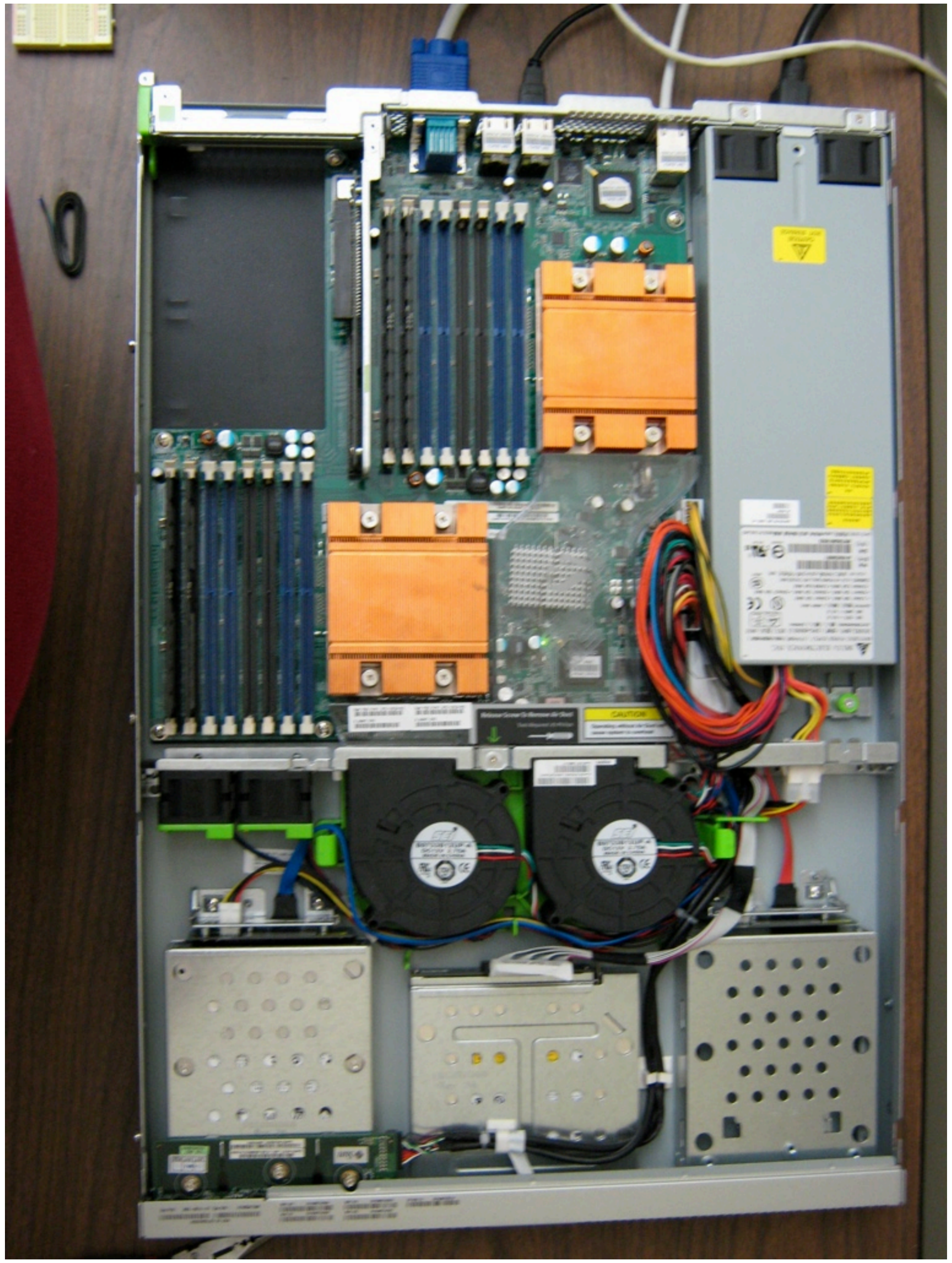
$$E_{dc} = E_{system}$$

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



- Three DC voltage domains
  - –12Vdc, 5.5Vdc, 3.3Vdc
- 5.5V and 3.3V domains limited to 20% of rated voltage

Model: Components

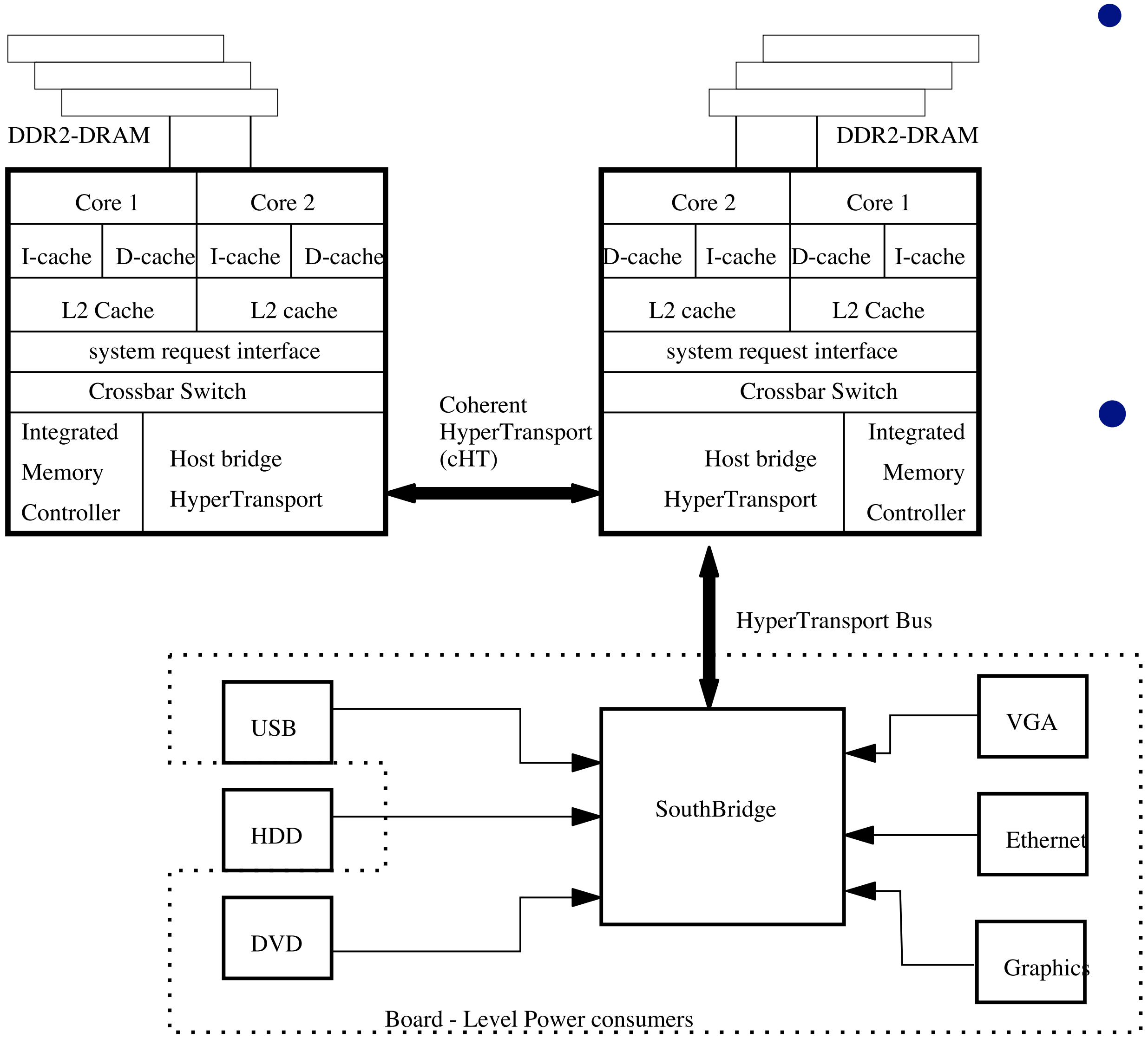


$$E_{dc} = E_{system}$$

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

Model: Processor

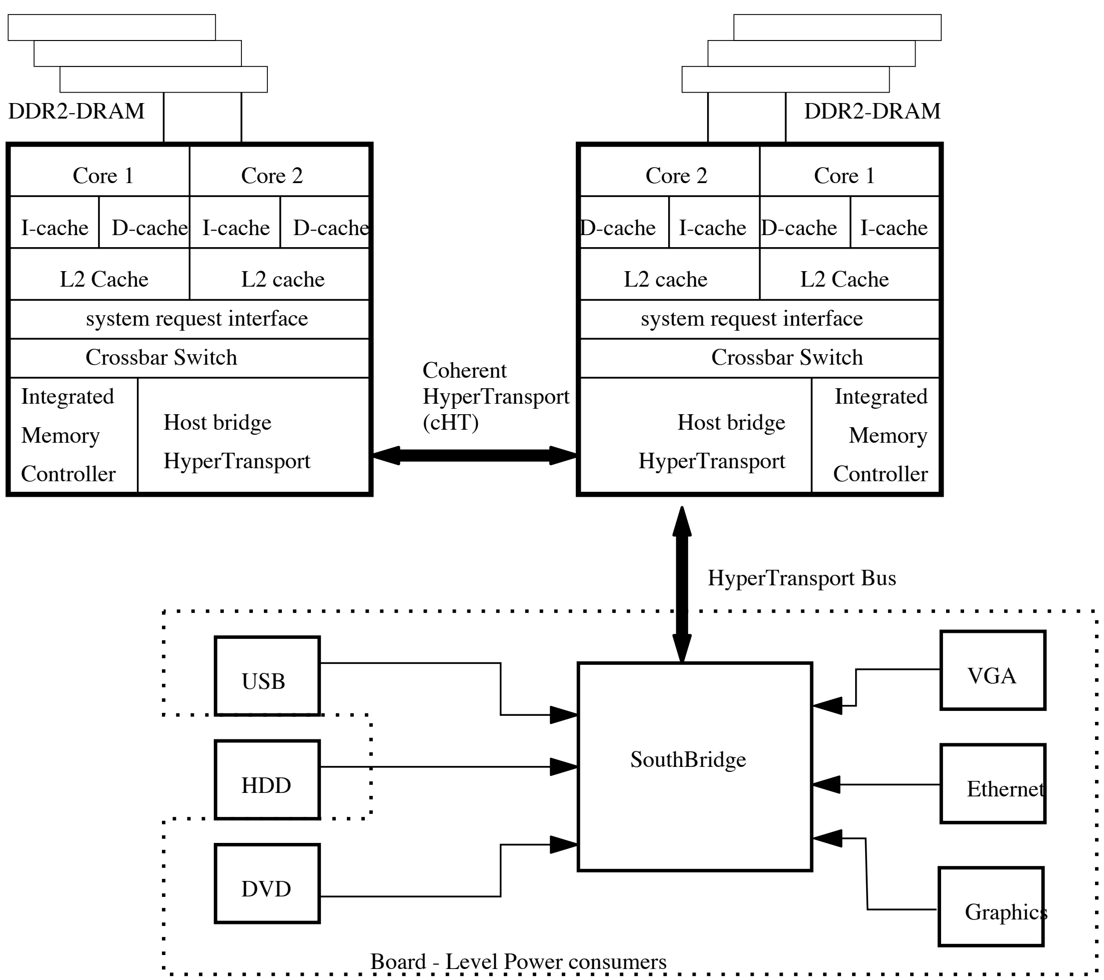
$$P_{proc} = \mathbf{H} \cdot \mathbf{X} = [\beta_0 \cdots \beta_{10}]^{\mathbf{T}} \cdot [\mathbf{Var_0} \cdots \mathbf{Var_{10}}]^{\mathbf{T}}$$



- Processor as black box
  - Energy = f(workload)
  - Manifests as heat
- HyperTransport
  - Data bus between cores and Southbridge
  - Reflects amount of data being processed by a processor or its cores

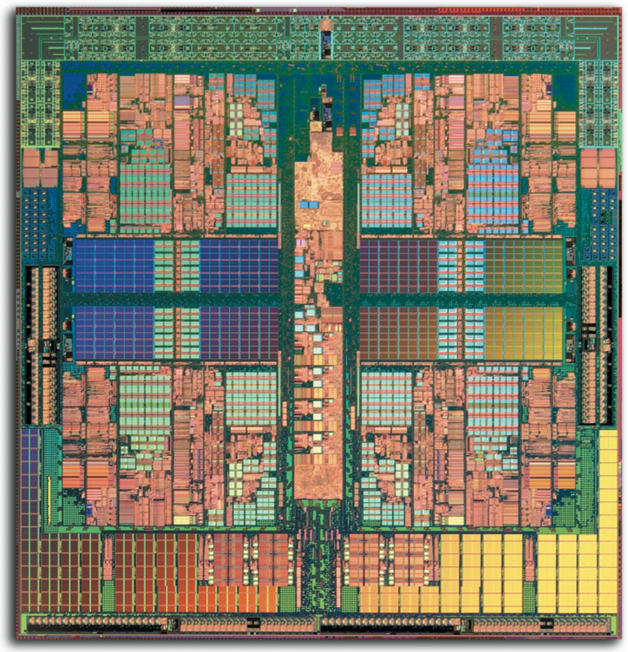
Model: Processor

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



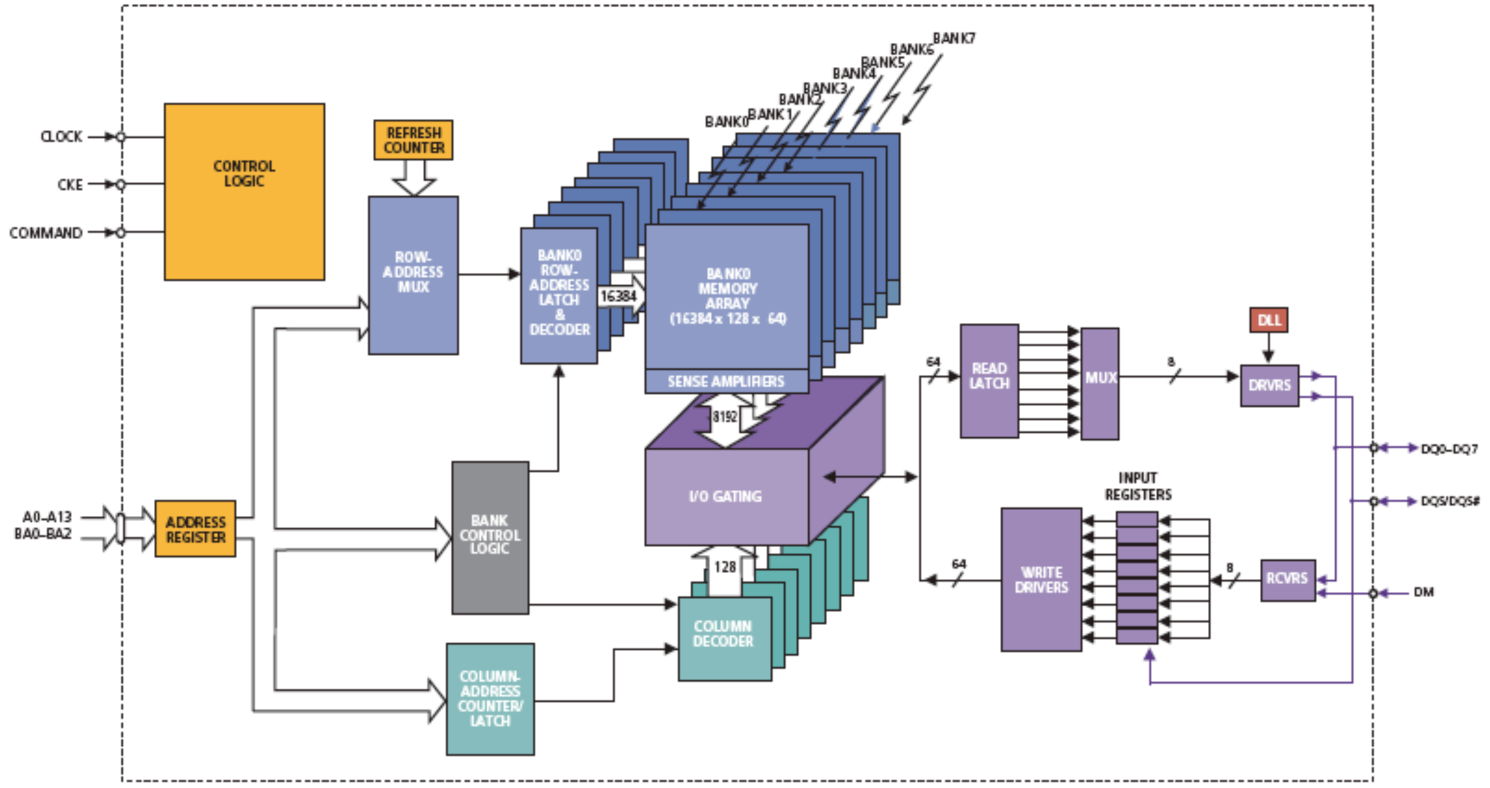
- The vector **X** contains variables for
  - Ambient and die temp.
  - HT1 and HT2 transactions
  - L2 cache misses per core

Model: Processor



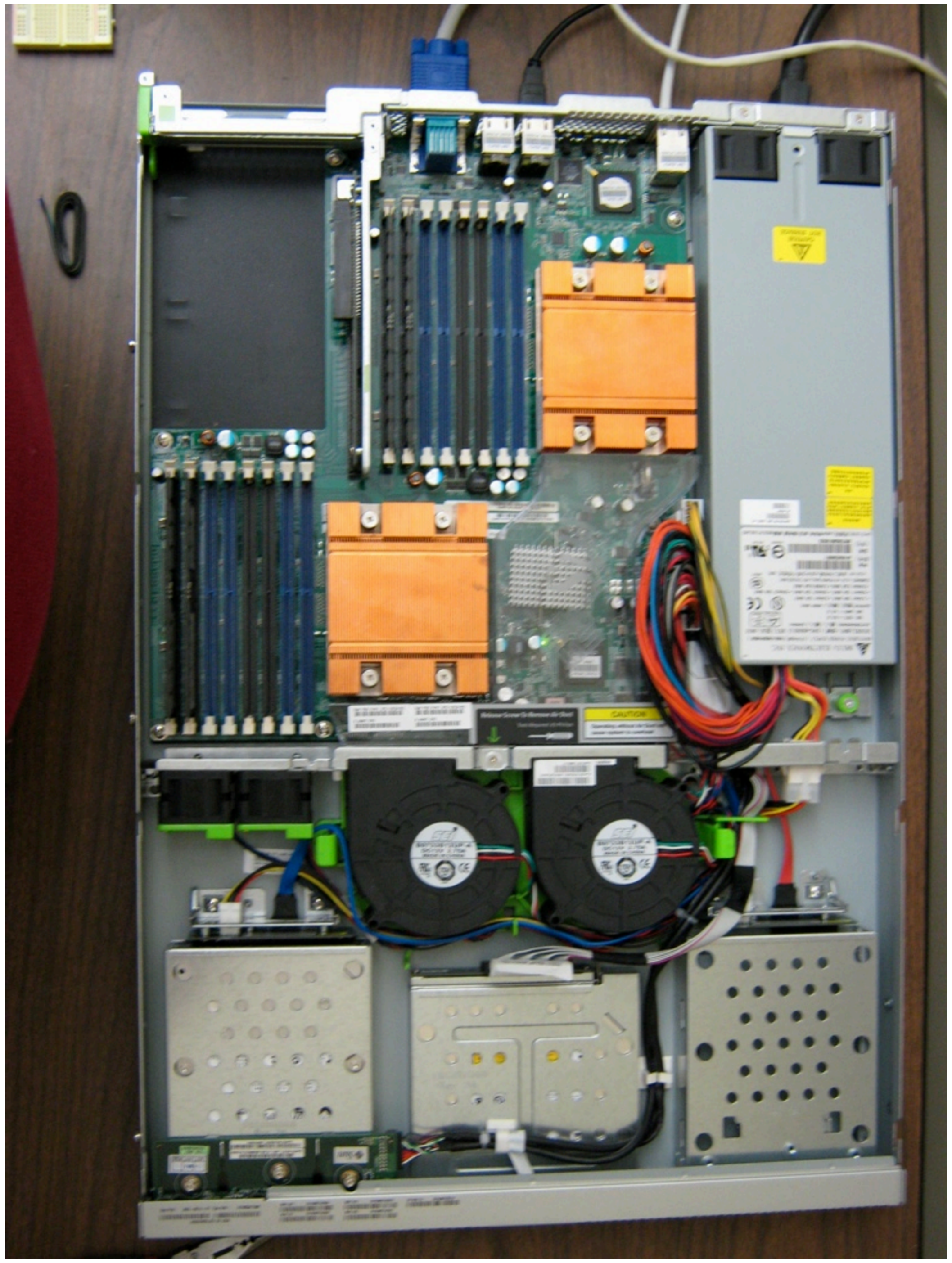
- Processor metrics
  - Performance counters
  - Avoid multiplexing as much as possible
- System metrics
  - Operating system metrics
  - Access through IPMI, sar, and other standard tools

Model: Memory



- DRAM Read/Write power + background power = known quantities
- Performance counters exist for measuring the count of highest level cache miss
- Combine these to compute the energy consumed

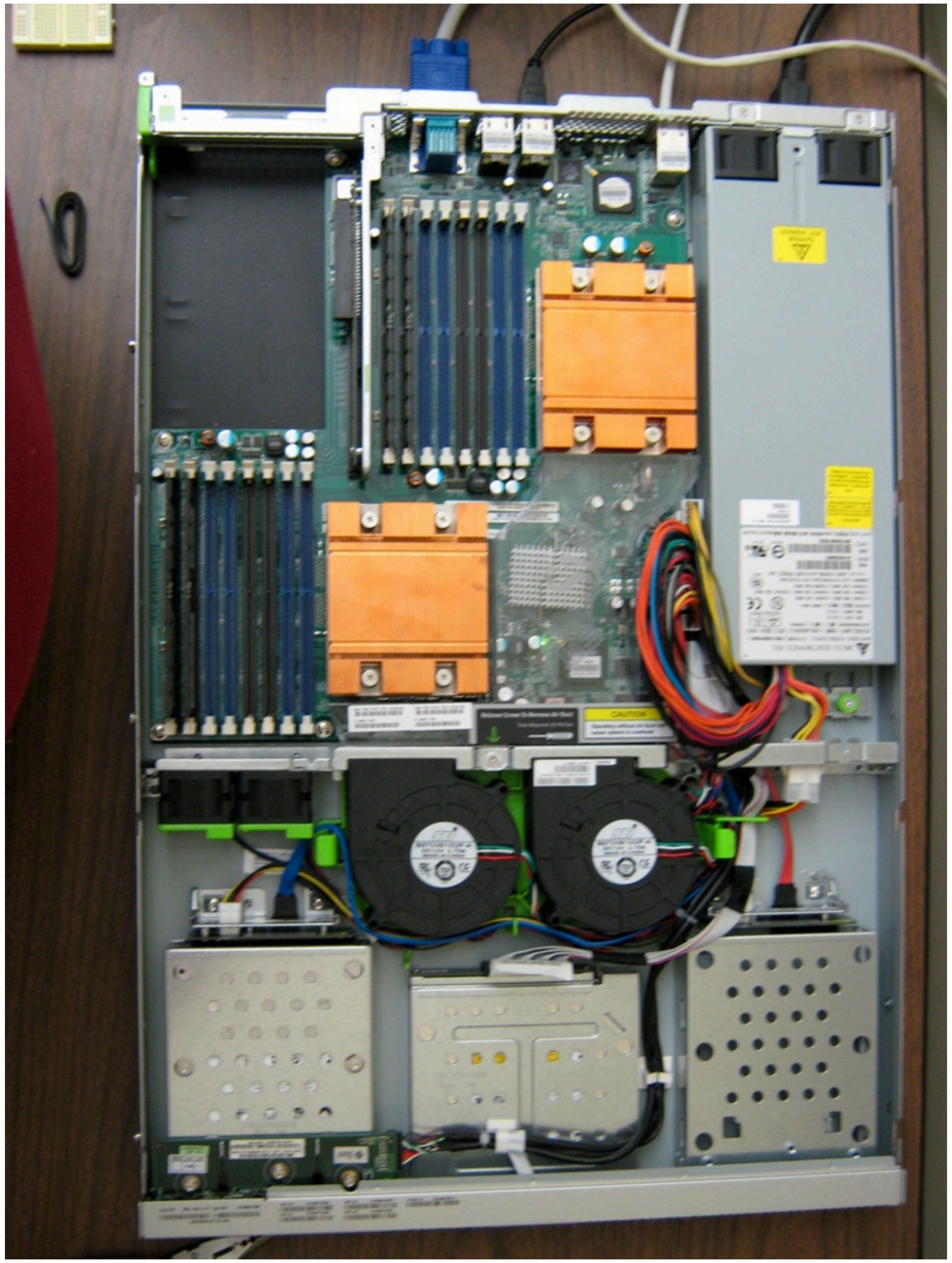
Model: Board



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

- System components that support the operation of the machine
  - –Typically in the 5.5Vdc and 3.3Vdc power domains
  - –Measured by current probe

Model: Electromechanical



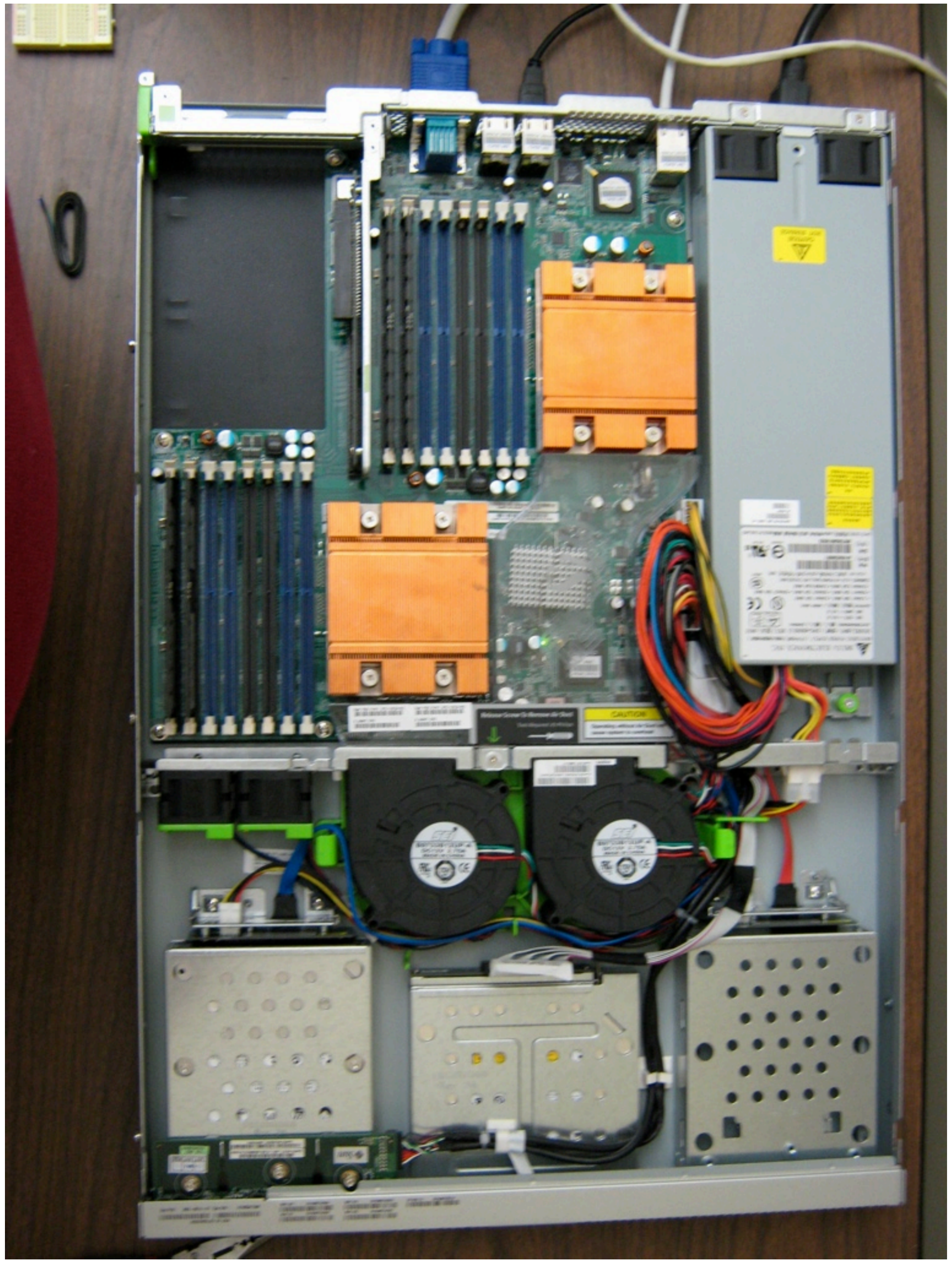
- Need to account for energy required to cool
  - –No performance counters
  - –Can measure power drawn by the fans
  - –System reports time slice
- Energy consumption by optical devices

Model: Storage

$$
\begin{aligned}
E_{hdd} \quad &= P_{spin-up} \times t_{su} + P_{read} \sum N_r \times t_r \\
&+ P_{write} \sum N_w \times t_w + \sum P_{idle} \times t_{idle}
\end{aligned}
$$

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)

Model: Components



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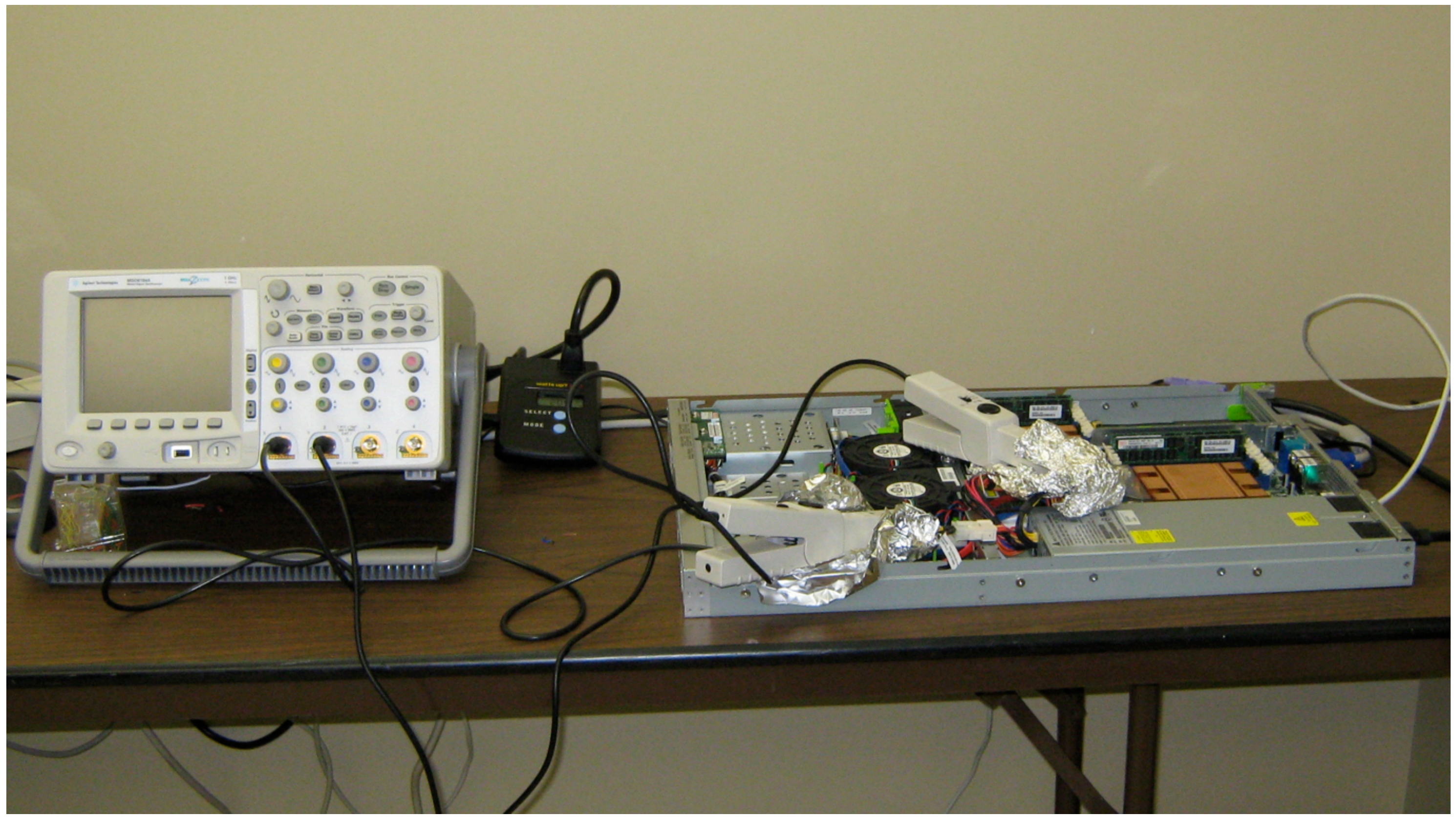
Application of Model



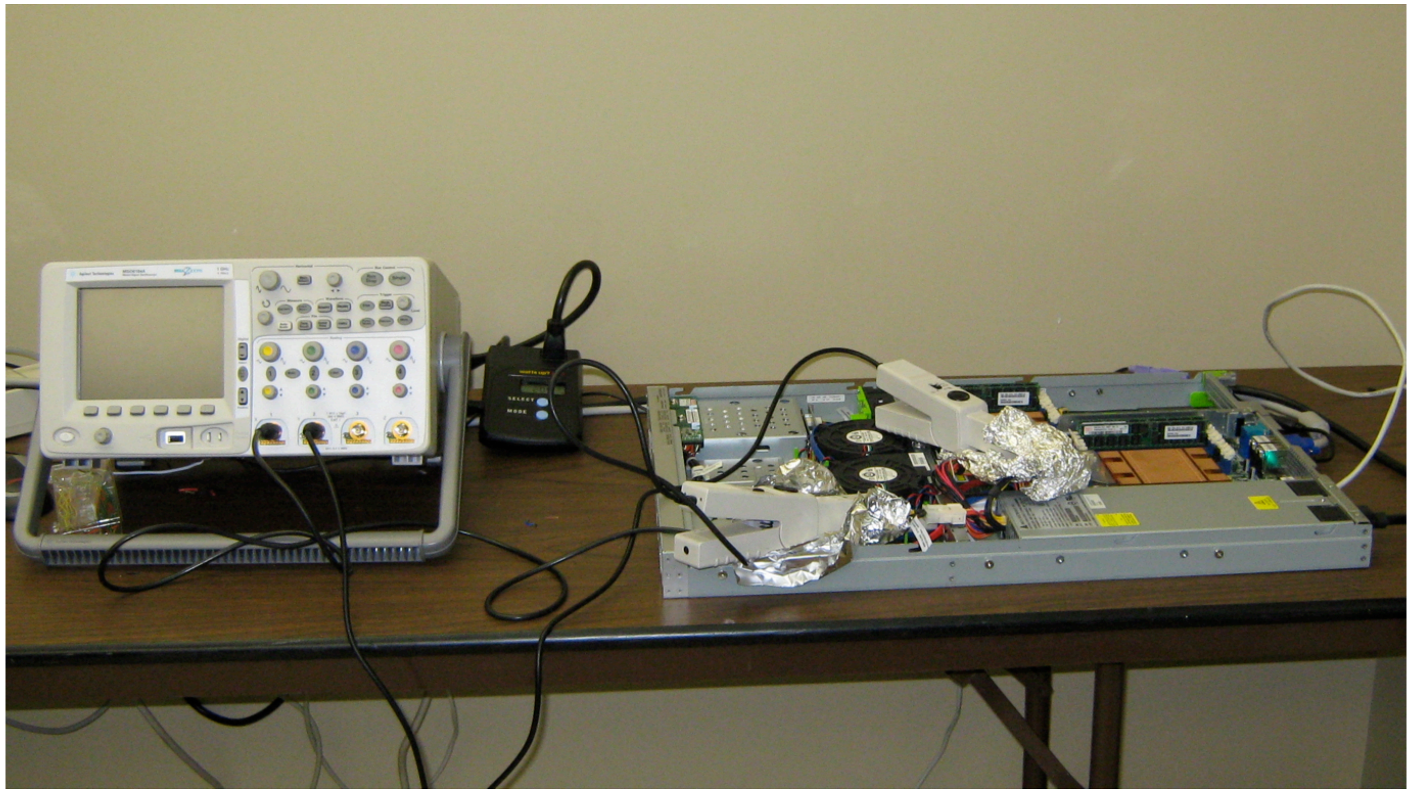
System Under Test

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

SPEC CPU2006 Benchmarks

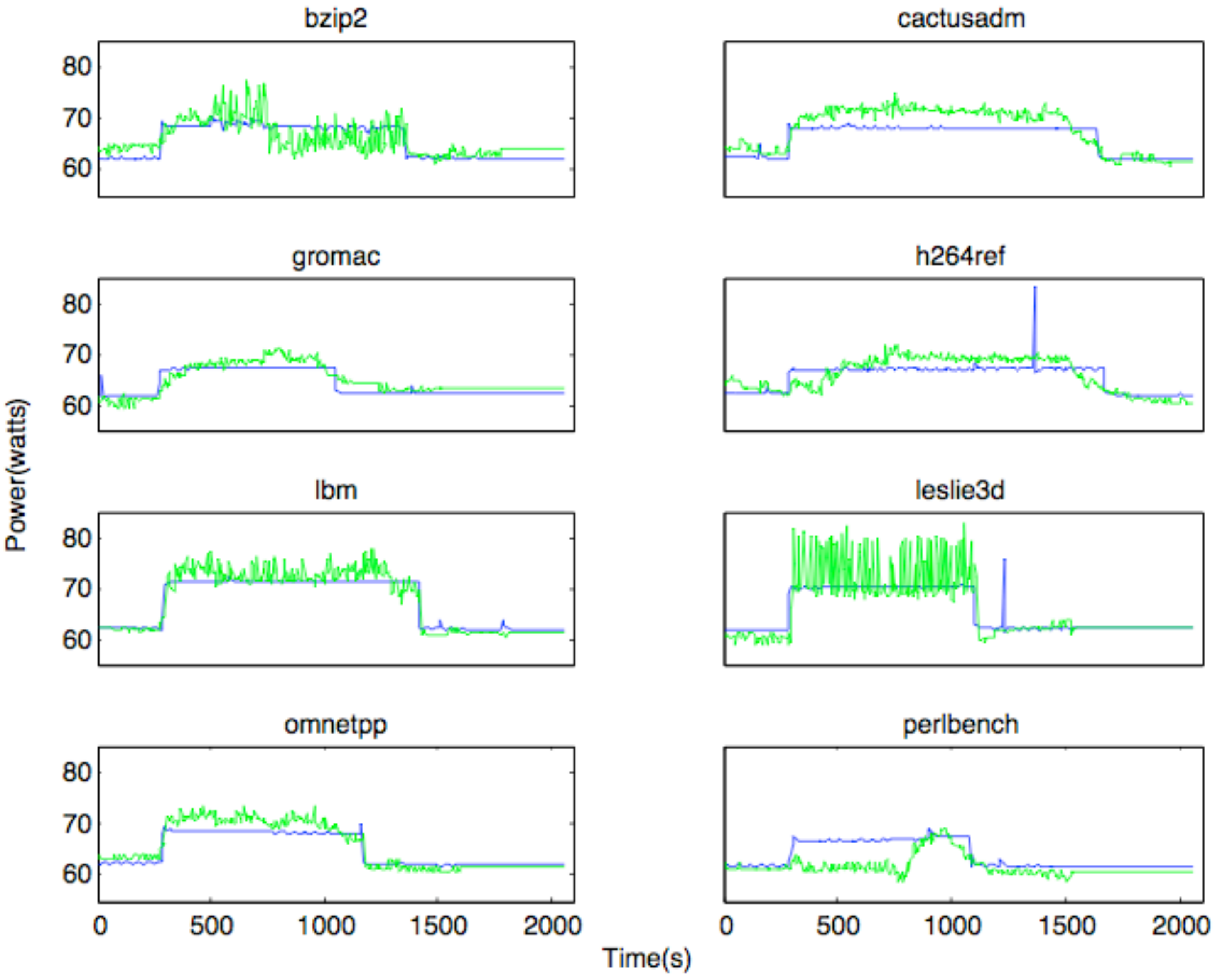
Benchmark		***Type***	***Use***
perlbench	C	Integer	PERL Programming Language
bzip2	C	Integer	Compression
mcf	C	Integer	Combinatorial Optimization
omnetpp	C++	Integer	Discrete Event Simulation
gromacs	C/Fortran	Float	Biochemistry/Molecular Dynamics
cacstusADM	C/Fortran	Float	Physics/General Relativity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

Application of Model



- Sample for each benchmark
- Use geometric mean of samples to create a predictive model for this configuration
- Create linear regression model for each benchmark and geometric mean
- Use ANOVA techniques to compare
- Regression model built from geometric mean
  - Adjusted R-square value of 0.965
  - Projected error of 3.5%
  - 95% confidence level

Evaluation



- Use model constructed from geometric mean to predict for each benchmark used to calibrate model
- Error range from 2.0% to 3.5% for each benchmark
- Noise in prediction results from use of geometric mean

Observations

- One model to rule them all?
- Inputs
  - How many PeC at one time?
  - Lack of standardization for environmental sensors
  - Placement of sensors
- Linear or non-linear?
- Calibrate/evaluate using other HPC benchmarks
- Other architectures?
  - Intel Xeon
  - Cell BE
- How well does the model scale to larger number of cores?

Next steps

- Calibrate with larger set of benchmarks
  - Disk and memory benchmarks
  - Other HPC benchmarks
- Evaluate and extend model for other architectures
  - Intel Xeon
  - Cell BE
- Incorporate model into a energy conserving process scheduler

Acknowledgements

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