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Professor Tom Conte
Editor-in-Chief
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Dear Professor Conte:

We thank the reviewers for the time and effort required for their thorough reviews of our submission and greatly appreciate their candid and valuable comments, which clearly strengthen our manuscript. We have taken all comments into full consideration, addressing them in the revised manuscript, as detailed in sequence. Please find a detailed response to the review comments attached to this cover letter.

Respectfully yours,

Adam Wade Lewis

encl: (1) Response to Reviewer #1

TACO-2010-27: Review Response: Reviewer #1

First of all, we greatly appreciate your time and effort put toward your candid and informative review, which helps to improve the quality of our submission. The following lists our responses to your concerns and comments made on our initial manuscript. Hopefully, we have addressed all your concerns and comments to your satisfaction.

First Comment/Concern:

> *First, again, I think the paper title needs to be clearer. As it stands, it refers to an "approximation of an estimation". Based on your response, CAP is an instantaneous power estimation method, and I think "Run-time Energy Consumption Estimation based on time-series approximation.." might be more representative.*

Response:

The title of our paper has been adjusted to address the reviewer's concern.

Second Comment/Concern:

> *Next, it is still not clear to me where the benefit of CAP comes from. For example, can you give an example to where simple, Mantis-like approaches do not perform well for the workloads you evaluate?*

Response:

The issue of workloads inadequately addressed by Mantis-like approaches has been addressed in recent work, particularly by [Varsamopoulos et al. 2010],[Kansal et al. 2010], [Hsu and Poole 2011], and [McCullough et al. 2011]. In [Hsu and Poole 2011], the authors examined 177 measured results of the SPECpower_ssj2008 benchmark published from December 2007 to August 2010 to statistically analyze the shape of the power curves over time and evaluate the effect of the aggressive power-management schemes introduced since the publication of [Economou et al. 2006]. Both this work and [Varsamopoulos et al. 2010] found that the resulting power curve are neither linear nor convex, which invalidate an underlying assumption behind models such as MANTIS. For example, in [McCullough et al. 2011], the authors found that MANTIS (adjusted for evolution of processor performance counters since the publication of [Economou et al. 2006]) suffered mean prediction error of 10-14% for the SPEC CPU2006 suite, the PARSEC multicore benchmark suite, and synthetic micro-architecture benchmarks that focused on components of system energy consumption. In particular, the authors found that MANTIS suffered from pronounced error behavior in cases of high utilization and low IPC (for instance, the `canneal` benchmark from the PARSEC suite, the `Bonnie` I/O benchmark and a synthetic system stress benchmark).

The causes of this behavior is considered by recent work cited in our paper. In [Kansal et al. 2010], it was observed that that behavior of SPEC CPU2006 benchmarks in both physical and virtual machine environments is rarely uniform in distributing tasks across multi-core processors. It was postulated in [McCullough et al. 2011] that multi-core processors have evolved to the point where features cannot be abstracted easily to permit linear models to accurately predict the behavior of these systems.

We have added additional material to our discussion of prior work that considers the issues raised by these references.

Third Comment/Concern

As you argue in the beginning of the paper, these approaches relate usage information to the power of the entire system rather than its individual components. So what kind of improvement do we see with the CAP approach with subcomponent prediction?

Response:

CAP is a full-system model much like MANTIS and other approaches. As such, our intent is to predict the individual sub-components energy consumption but to attribute the contribution of these components to the total. In doing so, we address the concerns raised by [Kansal et al. 2010] and [McCullough et al. 2011] in regard to the factors that contribute to non-linearity in the power curves of multi-core processors. As shown in Tables VIII and IX in our work, we see improvement in both average and maximum error for CAP as compared to linear AR, MARS, and EWMA predictors, in particular when we consider a more recent processor such as the Intel processor used in our study.

Fourth Comment/Concern:

> *Along the same lines of comparative evaluation, as I had mentioned in the original review, there are other prior approaches that predict future behavior based patterns/statistics. How does CAP compare to even simplistic approaches for future behavior prediction like last-value, or simple exponentially-weighted moving averaging? I suspect the resulting power curves would look very similar, albeit slightly shifted versions of what is depicted in Figures 7/8. A simple error analysis can demonstrate the value of CAP, in addition to those included for AR and MARS.*

Response:

The reviewers intuition about the shape of the power curves is correct; some similarity exists in the shape of CAP and exponentially-weighted moving averages (EWMA) predicted power curves. However, EWMA demonstrates error behavior similar to the error behavior of AR(1) and MARS predictors, with average errors between 1.0% and 1.8% and maximum errors between 6.9% and 9.2% for the AMD Opteron processor (Intel Nehalem: average error: 1.8% - 5.0%; maximum error: 27.3% - 32.4%).CAP differs from methods such as EMWA by using points on the attractor to approximate the next entry in the series. By doing so, we improve upon the approximation error as compared to EWMA and others. In addition to the additional information in Tables VIII and IX, we provide additional discussion in Section 5.3 and the Appendix on this topic.

Fifth Comment/Concern

> *I am also still not sure how the four SPEC benchmarks can help verify the sub-component power models beyond memory per your response. Do you see these benchmarks exercising these components at different rates and creating different dynamic power? Section 5.1 para-1, suggests these four were selected as workloads more common to server workloads. Can you please explain what this means? Can you also further provide an example to sub-component power estimations?*

Response:

Four benchmarks from the SPEC CPU2006 benchmark suite were used for the evaluation purpose, as listed in Table **??**), and they are different from those employed earlier for CAP creation (as listed in Table V). It is noted that selection of benchmarks for both calibration and evaluation were selected to sufficiently exercise processor, cache, and memory again per the decision criteria in [Phansalkar et al. 2007], with the additional criterion of selecting workloads more common to server environments. For example, the integer benchmarks `astar` and `gobmk` were selected based upon the benchmarks branch and memory access patterns as compared to the benchmarks used for calibration. A similar rationale was used in the choice of `calculix` and `zeusmp` benchmarks from the suite of floating point benchmarks. The benchmarks in the SPEC CPU2006 suite are designed so that the integer workloads in the benchmark suite map to the performance of business applications found in the data center while the floating-point workloads map to scientific calculations found in a high-performance computing environment [Cisco Systems 2010]. In this case, the four benchmarks used for evaluation best represent the type of workloads expected in the evaluation environment.

Sixth Comment/Concern

> *Last, I am still not clear how these servers exhibit just 60W-70W and 45W-70W idle-active power ranges. Are you showing ONLY CPU power? Can you please provide more details to how you confirm this with data provided by server manufacturers? Based on what I had seen, Sun quick reference reports 450W power consumption for Sun Fire 2200 and Dell PowerEdge Power and Performance Data Sheet reports Min:138W, Typical:285W, and Max:425W, which are more in line with what I expected.*

Response:

The values reported in Figure 7 & 8 were showing only CPU power. These figures have been adjusted to show full system power.

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