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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 revision 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. Please find a detailed response to the review comments raised by Reviewer #1, in the enclosed attachment of this cover letter.

Respectfully yours,

Adam Wade Lewis

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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 earlier revision. 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 according to your suggestion.

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 unveiled 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 our work and [Varsamopoulos et al. 2010] found that the resulting power curves were 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]) exhibited the 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, [McCullough et al. 2011] 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 error behavior were described and discussed by recent work cited in our paper. In particular, [Kansal et al. 2010] observed that the error 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 (as attempted by MANTIS-like modeling).

We have added additional materials 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, aiming to predict the individual sub-components energy consumption for attributing these components to the total energy consumption. 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 IX and X in our revision, both average and maximum error for CAP are fare less as compared to those of 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:

Your intuition about the shape of the power curves is correct; some similarity exists between the shape of CAP and the power curves predicted by exponentially-weighted moving averages (EWMA) predicted power curves. However, EWMA demonstrates error amounts similar to those 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 lower the approximation error as compared to the error amounts of EWMA and others. In addition to the extra information included in Tables IX and X, 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:

Benchmark selection in our work is based upon the decision criteria listed in [Phansalkar et al. 2007], with the additional criterion of selecting benchmarks from the SPEC CPU2006 suite most representative of scientific computing workloads [Cisco Systems 2010]. These benchmarks, as you observed, primarily focus on the processor, cache, and memory; however, the execution of them affects the entire system, as noted in [Ye et al. 2007] and confirmed by examining the details of the PeCs collected in our study. The following table contains averages of the fan speed, the number of HyperTransport bus transactions, and the amount of bytes read/written to disks for the four benchmarks over the same period during their execution on the AMD Operton system in our testbed:

Benchmark	Fan Speed (RPM)	HT0	HT1	HT2	Disk Write KB
astar	3619	722292	9977044	8269956	10878
gobmk	3636	1263067	4075556	17123935	11622
calculix	3645	697783	11007822	8025921	23544
zeusmp	3640	1271058	17166529	14100030	1052

From the listed component data above, we can see that benchmarks exercise system components at different rates during their execution on the AMD machine. In general, benchmark execution affects the full system, beyond just the processor/cache/memory hierarchy. The above table results signify that data move from the processor via the HT2 HyperTransport bus to the disks in a different rate during benchmark execution. A similar situation is also observed when the benchmarks are executed on the Intel machine.

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 previously in Figures 7 & 8 included only CPU power, as you correctly pointed out. We have redrawn the two figures to show total system power consumption in this revision.