Power Signatures of High-Performance Computing Workloads

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Motivation

- Job scheduling as a Tetris game

- Driven by power usage patterns.

Can we:
  - Associate a pattern with each application?
  - Enhance scheduler with pattern information?
Motivation

- Qualitative patterns in applications’ traces
Talk Outline

● Research questions

● What is a power signature?

● Methodology:
  o Signature validation
  o Experimental setup

● Results

● Current and future work
Research Questions

● Can we summarize HPC workloads’ power behavior into distinctive signatures?

● Is such a signature consistent across
  o runs?
  o input data?
  o hardware configurations?
  o hardware platforms?

● How well (quantitatively) does a signature distinguish a workload?
What is a power signature?

A. The trace itself: vector of power measurements.

B. Statistical summary of the trace
How do we quantify the difference between two traces?

1. **Mean Squared Difference (MSD)**
   - Match power observations pairwise, and take MSD
   - Traces must be same length

2. **Dynamic Time Warping (DTW)**
   - Identifies similarities of two time series
   - Accounts for offsets and differences in periodic frequency
Feature-based Signature

What features are useful?

- **Basic statistics:**
  - 2-vector: < Maximum, Median >
  - (Divide each by trace’s minimum power)
  - Call this **MaxMed**

- **More involved statistics that have been found useful in time-series clustering:**
  - Standard Deviation + 11 other features
  - Augmented with **MaxMed**, call this **stat14**.
Signature Validation

- Clustering: “optimally” partition a set of traces

- Classification: automatically identify the label (e.g. workload) of a trace
Signature Validation: Clustering

- **Input:**
  - Data points (traces)
  - Notion of distance (signature)

- **Output:** Partition

**Algorithms:**
- **kmeans:** centroid-based clustering
- **dbscan:** density-based clustering
- **hclust:** hierarchical clustering
  - dendrograms
Signature Validation: Clustering

Our signature is good if the partition is good. How do we know a partition is good?

1. Look at the partition qualitatively: Are workloads grouped together?

2. Quantitatively compare partition to some "ideal" reference.
   - Example ideal reference: grouped by workload
Signature Validation: Classification

Algorithm: Random forest

Leave-one-out accuracy measures a signature’s utility

Bonus: Variable importance measures
Experimental Setup

255 power traces from 13 benchmarks.

- (Baseline)
- SystemBurn*:
  - FFT1D
  - FFT2D
  - TILT
  - DGEMM
  - GUPS
  - SCUBLAS
  - DGEMM+SCUBLAS

- Synthetic: Power Model Calibration**
- Sort
- Prime95
- Graph500
- Stream
- Linpack-CBLAS

** Rivoire et al, Hot Power, 2008

* Josh Lothian et al., ORNL Technical Report, 2013
## Experimental Setup

<table>
<thead>
<tr>
<th></th>
<th>S1 (RR)</th>
<th>S2 (OC)</th>
<th>S3 (LC)</th>
<th>S4 (RF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CPU</strong></td>
<td>AMD Athlon 65 X2 4800+ @ 2.5 GHz</td>
<td>Intel Core i5-750 @ 2.67GHz</td>
<td>Intel Core i5-750 @ 2.67GHz</td>
<td>Intel Core i7-3770 @ 3.40GHz</td>
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<tr>
<td><strong>RAM</strong></td>
<td>4 GB</td>
<td>8 GB</td>
<td>8 GB</td>
<td>8 GB</td>
</tr>
<tr>
<td><strong>GPU</strong></td>
<td>GeForce 9800gt</td>
<td>GeForce GTX 285</td>
<td>GeForce GTX 650 Ti 1GB</td>
<td>GeForce GTX 670 2GB</td>
</tr>
</tbody>
</table>

**Watts Up? Pro** power meter reports power consumption once per second.
Clustering Results

- OCRR data
  - n=30
  - 6 workloads (different input configurations)
- Algorithm: hclust
- Signature: raw trace
- Distance: MSD

2-clustering:
- Top: Stream, Prime95, Linpack-CBLAS (CPU-intensive)
- Bottom: Calib, Baseline, Sort
Clustering Results

- OCRR data
  - n=30
  - 6 workloads (different input configurations)
- Algorithm: hclust
- Signature: stat14
- Distance: Manhattan

4-clustering:
- Stream, Prime95, Linpack-CBLAS
- Sort
- Baseline
- Calib
Clustering Metric

Ideal clustering: by workload.

Info-theoretic measure of partition similarity: Adjusted Normalized Mutual Information

(Derived from NMI)

- NMI = (Mutual information) / (Joint entropy)
- NMI is between 0 (worst) and 1 (best)

- Expected ANMI of two random partitions is 0.
Clustering Results

- **Data:**
  - LCRF (n=225)
  - LC (n=111)
  - RF (n=114)
- **Algorithm:** hclust
- **Signature:** MaxMed

Signatures may be more consistent *within* hardware platform
Clustering Results

- Data: LC (n=111)
- Algorithm: hclust

MaxMed and DTW signature methods are more effective than Stat14 and MSD
Classification Results

- Trained a random forest classifier on LCRF data (n=225)
- Using **MaxMed** or **Stat14** yields leave-one-out accuracy >80%
Classification Results

Gini variable importance suggests:

- **MaxMed** is a good subset of **Stat14**

- **Try Stat3:**
  < Normalized Maximum, Normalized Median, Serial Correlation
  >
Classification Results

- **Stat3** classifier labels traces with >85% accuracy
Conclusions

- We evaluated different types of signatures:
  - Time-series-based
  - Feature-based

- Some workloads have unique signatures, some workloads are less easily distinguished from others.

- Signatures can distinguish workloads across hardware platforms, but are more effective given data from a single machine type.
Current and Future Work

● Expand to:
  o Heterogeneous workloads
  o MPI/distributed workloads
  o Finer-grained or coarser-grained samples

● Online workload recognition

● Workload-aware energy-efficient scheduling
Acknowledgements

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Afterthought: Clustering Again

- Data: LC (n=111)
- Algorithm: hclust

Stat3 is not obviously better than MaxMed for clustering
Backup: More Clustering Results

- Data: LCRF (n=225)
- Algorithm: hclust

The result holds for multiple platforms:

MaxMed and DTW signature methods are more effective than Stat14 and MSD