Energy Reduction in Cloud and HPC: Design and Implementation of a Blind Methodology

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High performance computing (HPC)

Example of HPC system.

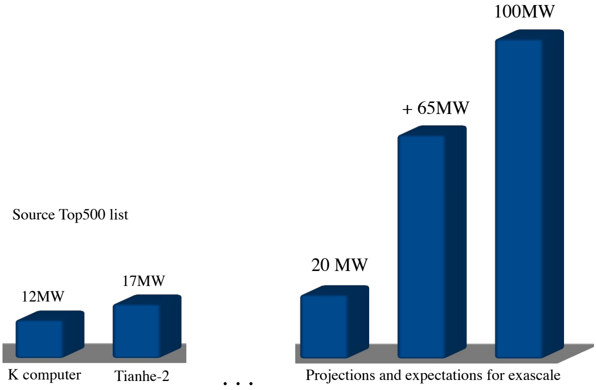
- User perspective
  - Services that enable new level of innovation and insights
- Technological perspective
  - Cluster of servers, supercomputers, software, tools, interconnects, storage, and services

High Performance Computing (HPC) System's Usage

As the demand for processing grows, HPC is likely to interest all businesses, R&D dept., and academic research

- **Computer aided engineering:** transportation, structural, mechanical design, automotive testing and design
  - Architects use HPC to evaluate building in realistic scenarios through simulation
- **Bio-science and the human genome:** drug discovery, disease control
- **Chemical engineering:** process and molecular design
- **Economics:** a bank uses HPC to analyse high volume of digital transactions

HPC systems and energy consumption



High Performance Computing (HPC) System Design

- **Place great emphasis on a few components:** processor architecture, memory subsystems, storage subsystems and communication subsystems
  - Performance of cpu-intensive workloads depends on processor architecture
- **Guarantee performance on average over varied workloads.**
  - Often result in energy inefficiency
    - Workloads variability and/or variability in a specific workload

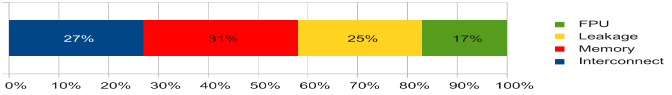
Energy reduction in HPC

- **Hardware based initiatives**
  - Multi-configuration (processor, NIC), more energy efficient (GPU), and low power hardware (DDR3, SSD)
- **Software based solutions: application oriented**
  - Rely on multi-configuration hardware
  - Analyse the behaviour or the structure of the application and take energy reduction decisions
    [Kimura et al. 2010] , [Spiliopoulos et al. 2011], [Carrington et al. 2012]

Energy reduction in HPC (cont.)

Software solutions fail to find their way into real HPC deployments

- Complex in nature
  - Vast technical details behind the proposed solution
  - Thorough understanding of the application at hand
- HPC applications are often too complex to be rewritten or modified. “I just added one line and it is no longer working!”
  - limit the scope of application oriented energy reduction techniques
- Often do not reflect current trends



Projection of energy distribution in an exascale system. [Broekema et al. 2012]

Global Objective

A user friendly methodology for reducing the energy consumption of large-scale and distributed infrastructures without a priori knowledge of applications.

1. A three step methodology
   - Phase detection
     - Methodology
     - Case study: a real life system
   - Phase/workload characterization
   - Phase identification and system reconfiguration
     - Identification of recurring phases
2. Experimental results and discussion
   - MREEF: extension to cloud environments
3. Conclusions and Perspectives

Overview

Phase detection

Discover system's runtime execution patterns

Phase characterization

Associate useful information with known execution patterns

Phase identification and system reconfiguration

Reuse of optimal configuration information for recurring phases

Overview and definitions

Step 1

Definition:

- Phase: region of execution of the application/system stable with respect to a given metric
- System: computing or storage node

Overview:

- Detect changes in the system's behaviour that result from changes in the behaviour of programs running
- Two complementary approaches
  - "Power-based phase detection": make use of the system power profile
  - **Execution vector based phase detection**

EV-based Phase Detection: system observation

Step 1

- **Processor and memory activities**
  - Hardware performance counters
    - e.g. *cache_ref* (number of references to the cache), *branch_ins* (number of branch instructions), *cache_misses* (number of cache misses) . . .
    - Available to all processors, low overhead, used outside of any applications
    - Intrusive (accessed at system runtime)
- **Disk and network usage information**
  - System statistics (*/proc/stat*)
    - Disk read and write counts
    - Network byte send and received counts

EV-based phase detection: execution vector (EV)

Step 1

Definition:

- Column vector whose entries are access rates of sensors – including hardware performance counters, network bytes sent/received and disk read/write counts.
  - access per CPU cycles

Example:

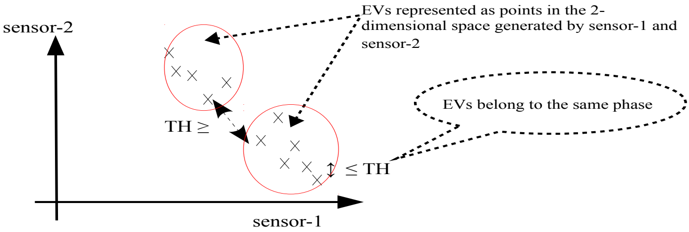
$$\begin{pmatrix} cache\_ref \\ branch\_ins \\ \vdots \\ byteSent \end{pmatrix}$$

EV-based Phase Detection

Step 1

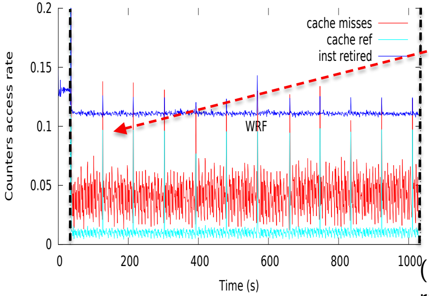
Similarity/resemblance between EVs is used for phase detection

- The Manhattan distance between consecutive EVs is the resemblance metric
  - Phase changes occur when the distance between consecutive EVs exceeds a given threshold (in percentage of the maximum distance between consecutive EVs).

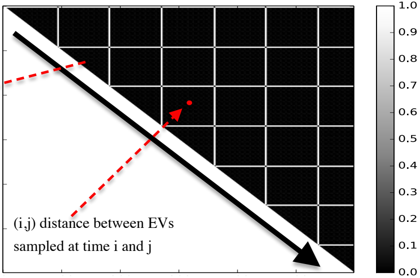


Detecting phases of a system WRF-ARW (Advance Research Weather Research and Forecasting) (1)

Step 1



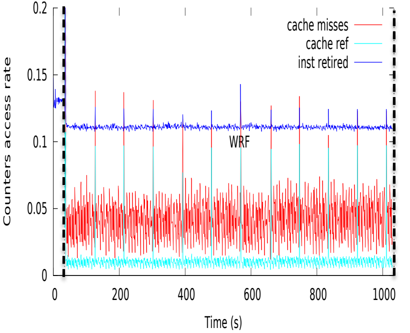
(c) Cache reference and miss rates along with branch miss rate (WRF-ARW)



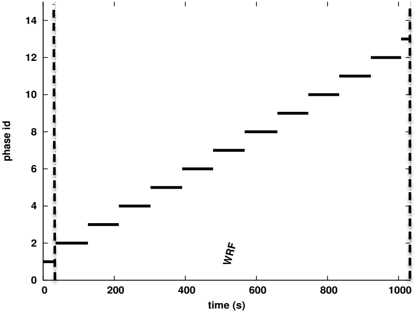
(d) Matrix of distances between EVs when running WRF-ARW.

Detecting phases of a system running WRF-ARW (Advance Research Weather Research and Forecasting) (2)

Step 1



(c) Cache reference and miss rates along with branch miss rate (WRF-ARW).



(d) Graphical view of system phase detection.

Contributions: Phase Characterization

- Detect system phase changes
- User friendly
- Has a limited overhead

[GreenCom 2013], [E2DC 2012]

Overview Phase characterization

Step 2

Objective: group phases into classes labelled so that similar phases according to system resource utilization appear under the same label

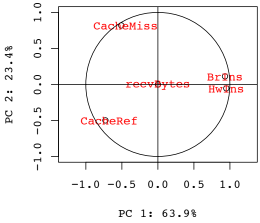
Six labels: compute-intensive, memory-intensive, mixed, network-transmit, network-received, IO-intensive

- Last level cache references per instruction ratio based (LLCRIR-based) phase characterization
- Statistical-based phase characterization
  - A low overhead phase characterization (Sensor-based)
  - Principal component based phase characterization (PCA-based)

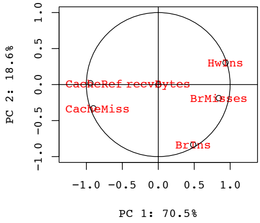
PCA-based phase characterization (1)

Step 2

Key idea: discover patterns shared by workloads of the same category
Variables have similar pattern w.r.t PC 1 and PC 2 in both cases



(a) Fourier Transform (FT).

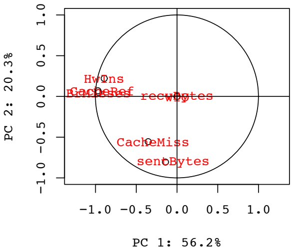


(b) Block Tri-diagonal solver (BT)

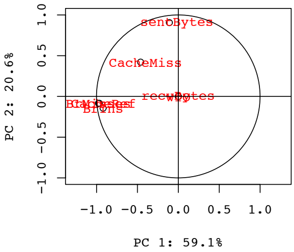
PCA-based phase characterization (2)

Step 2

For each type of phases, variables have similar pattern w.r.t PC 1 and PC 2



(c) idle_1, variables projected on PC1-PC2 plane.



(d) idle_2, variables projected on PC1- PC2 plane.

Contributions Phase Characterization

- Low overhead phase/workload characterization techniques
- Adapted to on-line use

[EE-LSDS 2013], [SBAC-PAD 2012]

Phase identification (1)

Step 3

Key idea: identify recurring phases

- Two main problems
  - Phases are often too long
  - A phase cannot be identified until it has completed

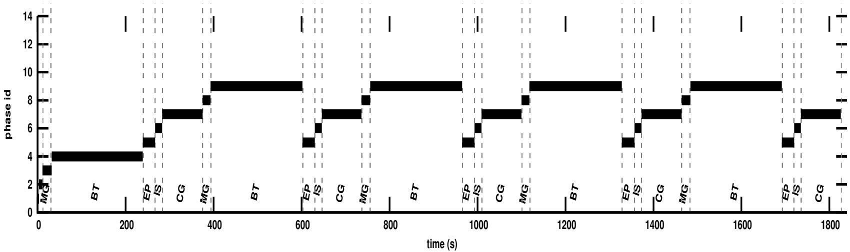
Phase representation

- Use of a single vector: the reference execution vector
  - The closest EV to the centroid of the group of EVs belonging to the corresponding phase
  - Phase identification boils down to comparing reference EVs

Phase identification (2)

Sample results

Step 3



Graphical view of system phase distributions resulting from five successive executions of *bench_1*.

Limited number of phases
Loosely identify all recurring phases

Phase prediction

Step 3

Key idea: reuse of configuration information for recurring phases/workloads

- **Partial phase recognition technique**
  - Identifies an ongoing phase with an existing, before its completion
- **Execution vector classification**
  - Instead of identifying complete phases
    - Match each newly sampled EV with known phases and make the reconfiguration decision for the next sampling interval

Basic principle:

- If the system is in a phases labelled say *l_1* at time T it is likely to be in a phase labelled *l_1* at time T + 1

Power saving schemes or green capabilities

Step 3

Def. Used to refer to any action destined to reduce the energy consumption of the system without "significant performance degradation"

- Performance degradation higher than 10% is significant

- **Management practices**
  - Platform selection through cross platform energy consumption
- **System reconfiguration**
  - Memory size scaling
  - CPU cores switch on/off
    - Suits best IO and communication intensive workloads
  - Traditional power saving schemes
    - Dynamic voltage and frequency scaling (DVFS), adaptive link rate (ALR), disk operating modes

Contributions: Phase Identification and System Reconfiguration

- Design to facilitate on-line use
- Offers alternatives to workload/phase prediction
- Introduce means for reducing the energy consumption of a system

[ICPADS 2012][FGCS 2013]

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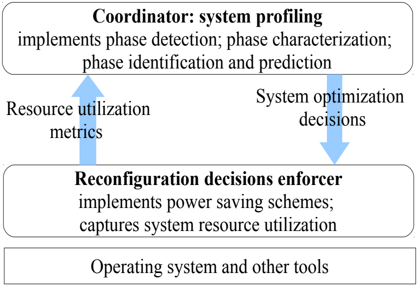
A Multi-Resource Energy Efficient Framework (MREEF).

An implementation of our methodology for reducing the energy consumption of large-scale and distributed infrastructure



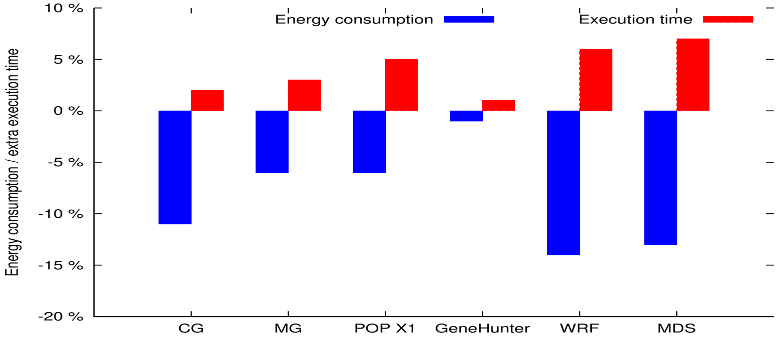
MREEF architecture overview.

- 3000 lines of codes
- Three programming languages:
  - R, Python, and C

MREEF EV classification related results: decentralized (1)

- Platform size: 34 nodes
- Each node implement the coordinator
- System reconfiguration decisions directed towards the processor through DVFS
  - Processor operating frequency for classes of workloads:
    - Compute intensive: 2.53GHz; mixed: 2.00GHz; memory-intensive: 1.87GHz; all others 1.20GHz
- Test workloads: CG and MG (9 nodes), GeneHunter and POP X1 (4 nodes), and WRF-ARW and MDS (25 nodes); they simultaneously share the 34 nodes
- Use of a majority-rule-based characterization algorithm
  - PCA-based, LLCRIR-based, and Sensor-based phase characterization schemes

MREEF EV classification related results: decentralized (2)



Comparison of MREEF (execution time and energy consumption) with the baseline on-demand configuration.

Energy reduction of up to 15% with less than 7% performance degradation

MREEF in cloud: context

- Virtual machines (VMs) often have contradictory needs
- Data centres operators often lack information regarding deployed VMs
  - Can be because of privacy concern
- HPC in cloud implies more variability in workloads

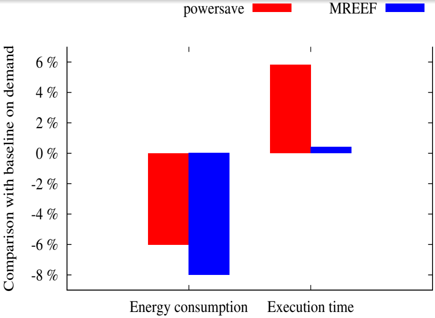
MREEF in cloud: experimental protocol and set-up

- 8 VMs deployed on a node having 8 CPU cores
- Each VM executes the following workloads 20 times
  - Cloud workloads:
    - Transactional database system (sysbench + MySQL)
    - Web application (siege + Apache HTTP server)
    - IO intensive application (IOzone)
  - HPC workloads: CG
- Three system configurations
  - on-demand, powersave, MREEF
  - Workloads are the same for each system configuration (a random execution order is provided to each VM)

MREEF in cloud: results

- MREEF configuration:
  - Majority-rule-based phase characterization for phase characterization
  - EV classification for workload prediction

MREEF reduces the energy consumption of up to 8%
Outperforms powersave



Baseline on demand versus powersave and MREEF in a cloud environment.

Conclusions

- A "user friendly" methodology for reducing the energy consumption of large-scale and distributed infrastructures
  - Phase detection, phase characterization and phase identification, and system reconfiguration
  - Allow users to implement their own power saving schemes
  - Takes into account all HPC subsystems and does not require any knowledge of applications from users
- MREEF: a software framework implementing the methodology
  - Energy improvement of up to 15 % without a priori knowledge of application and with less than 7% performance degradation
  - Decentralize and scalable architecture
- Extension to cloud shows that the methodology is not limited to HPC systems

Future directions

- More experiments and developments still need to be conducted in cloud environments
  - Additional power saving schemes: virtual machines migration and/or consolidation
- Investigate cases where we don't know the application, but its start and end time
  - Can help evaluating our methodology in production environments
- Investigate support for Memory size scaling in future operating systems