Dynamic voltage and frequency scaling for 3D Classical Spin Glass application

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***Abstract*—The power consumption of large-scale high performance computing (HPC) systems is becoming a crucial challenge in the context of increasing the performance regardless of energy consumption [1]. Therefore, finding ways to improve energy efficiency has become a main issue for HPC applications. Dynamic voltage and frequency scaling (DVFS) is a widely used and powerful technique for reducing energy consumption in modern processors. The present paper investigates energy efficiency of 3D Classical Spin Glass [2], [3] application using the performance, ondemand and powersave modes of DVFS method. The series of experiments show that the execution time of OnDemand and PowerSave is the same, while the OnDemand mode is better due to the power consumption and frequency balance for the system.**

***Keywords*—3D, Spin-Chains, HPC, Energy efficiency, DVFS.**

I. Introduction

The power consumption of large-scale HPC systems is becoming a crucial challenge in the context of increasing the performance regardless of energy consumption. Therefore, finding ways to improve energy efficiency becomes a main issue for HPC applications.

The Monte Carlo method is widely used not only by 3D Classical Spin Glass (SG) application [4] but also by many scientific applications, which allows researchers to solve very complicated problems that are not possible to solve analytically. In this paper we analyze the performance and energy consumption of 3D Classical SG application using the DVFS method, which allows changing the frequency of the system and reduce power consumption.

Several experiments have been conducted to achieve better performance of SG application [5] using the computational resources (128 processors, Myrinet inter-node communication) of Armcluster [6] without taking into account the power consumption aspect. To measure power consumption hardware facilities have to be used, and for each frequency change there is a need to reboot all cluster nodes. To avoid this problem a cloud simulation environment is used for accomplishment of the following tasks:

- The CloudSim DVFS package to obtain the power consumption.
- Changing the frequency rate automatically during the simulation.

The remaining content of the paper is organized as follows. The introduction of 3D SG application is presented in the Section 2. The experimental methodology in details can be found in Section 3 and the experimental results are given in Section 4. Finally, the conclusion and directives for future research are drawn in Section 5.

II. 3D spin glass description

The object of our investigation is the solid-state dielectrics, type of SiO2 glass (amorphous silicon dioxide). According to the numerical ab initio simulations [7], the structure of this type compound can be well described by 3D random network. The red and brown lattice points on the figure below correspond to different atoms, while the links between them correspond to covalent bounds [8].

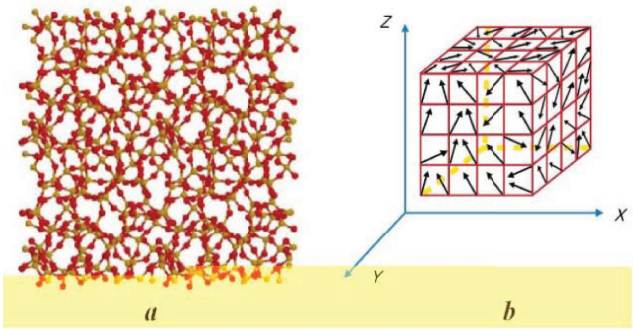

Fig. 1. The structure of amorphous silicon dioxide SiO2 is described by 3D random network with covalent bonds. Every silicon vertex (gold sphere) has 4 edges and every oxygen vertex (red sphere) has 2 edges.

As a result of charge redistribution in outer electronic shells, atoms of Si acquire the positive charge and atoms of O correspondingly the negative charge. Thus, we can consider compounds of this type as a disordered 3D system of similar rigid dipoles (hereinafter termed as a system of 3D disordered spins). Let us remind that under the similar rigid dipoles are meant the dipoles for which the absolute values are equal, and they don't vary under the influence of an external field.

We consider a classical ensemble of disordered 1D spatial spin-chains (SSC), where it is supposed that interactions between spin-chains are absent (later it will be called an ideal ensemble) and that there are N_x spins in each chain.

Despite some ideality of the model it can be interesting enough and rather convenient for investigation of a number of important and difficult applied problems of physics, chemistry, material science, biology, evolution, organization dynamics, hard-optimization, environmental and social structures, human logic systems, financial mathematics, etc., [9], [10]. Above mentioned type of ideal ensemble can be mathematically generated by the 1D Heisenberg spin-glass Hamiltonian without the external field:

$$H_0(N_x) = -\sum_{i=0}^{N_x-1} J_{i\,i+1}\boldsymbol{S}_i\boldsymbol{S}_{i+1}. \tag{1}$$

where S_i describes the i-th spin, which is a unit length vector and has a random orientation. In the expression (1) $J_{i\,i+1}$ characterizes a random interaction constant between i and i+1 spins, which can have positive and negative values as well. For further investigations it is useful to rewrite the Hamiltonian (1) in spherical coordinates:

$$H_0(N_x) = -\sum_{i=0}^{N_x-1} J_{i\,i+1}\big[\cos\psi_i\cos\psi_{i+1}\cos(\varphi_i-\varphi_{i+1}) + \sin\psi_i\sin\psi_{i+1}\big].$$

A stationary point of the Hamiltonian is given by the system of trigonometrical equations:

$$\frac{\partial H_0}{\partial\psi_i}=0, \qquad \frac{\partial H_0}{\partial\varphi_i}=0,$$

Afterwards using the Hamiltonian and the above mentioned equations it is easy to find the following system of trigonometrical equations:

$$\begin{aligned}
&\sum_{\nu=i-1;\ \nu\neq i}^{i+1} J_{\nu i}\big[\sin\psi_\nu - \tan\psi_i\cos\psi_\nu\cos(\varphi_i-\varphi_\nu)\big]=0,\\
&\sum_{\nu=i-1;\ \nu\neq i}^{i+1} J_{\nu i}\,\cos\psi_\nu\sin(\varphi_i-\varphi_\nu)=0, \qquad J_{\nu i}\equiv J_{i\nu}.
\end{aligned} \tag{2}$$

Also, in order to satisfy the condition of local minimum for H_0, it is necessary that the following inequalities (Sylvester conditions) are carried out:

$$A_{\psi_i\psi_i}(\Theta_i^0)>0, \quad A_{\psi_i\psi_i}(\Theta_i^0)A_{\phi_i\phi_i}(\Theta_i^0) - A^2_{\psi_i\phi_i}(\Theta_i^0)>0, \tag{3}$$

where $A_{\alpha_i\alpha_i}=\frac{\partial^2 H_0}{\partial\alpha_i^2}$ and $A_{\alpha_i\beta_i}=A_{\alpha_i\beta_i}=\frac{\partial^2 H_0}{\partial\alpha_i\partial\beta_i}$.

Here $\Theta_i^0=(\psi_i^0,\phi_i^0)$ denotes the angular configuration of the spin in case the condition of local minimum for H_0 is satisfied.

Finally, with the help of the equations (2) and the conditions (3) a huge number of stable $1D$ SSCs may be calculated and on its basis it is possible to further construct the statistical properties of $1D$ SSCs ensemble.

Let us note that exactly similar equations of stationary points also can be obtained if the full 3D Hamiltonian is used in the framework of short-range interaction model. That allows us to construct step by step a spin-chain of the specified length with taking into account the random surroundings. It is proved that at the limit of Birkhoff's ergodic hypothesis performance, 3D SG can be generated by Hamiltonian of disordered 1D SSC with random environment.

We have proved that it is always possible to construct a spin-chain in any given random environment, which will be in ground state energy (direct problem). We have also proved the inverse problem, namely, an environment can surround every spin-chain of the random environment so that it will be the solution in the ground state. Due to the series of experiments all the necessary numerical data were obtained via a large number of parallel simulations of the auxiliary problem in order to construct all the statistical parameters of 3D SG at the limit of ergodicity of 1D SSCs nonideal ensemble. As numerical simulations show, the distributions of all statistical parameters become stable after N_x X N_x independent calculations that are realized in parallel. The idea of 1D spin-chains parallel simulations, based on this simple and clear logic, greatly simplifies the calculations of 3D SG, which are still considered as a subset of difficult simulation problems.

SGs are the prototypical glassy systems most widely studied theoretically. Simulating SGs is a computing grand challenge, as their deceivingly simple dynamical equations are at the basis of complex dynamics, whose numerical study requires HPC resources. In a typical spin-glass model, the dynamical variables, one calls them spins, are discrete and sit at the nodes of discrete D-dimensional lattices. In order to make a contact with the experiments, we need to follow the evolution of a large enough lattice, say a 3D system with 80x80x80 sites, for time periods of the order of 1 s. One Monte Carlo step (MCS) - the update of all the 80x80x80 spins in the lattice - roughly corresponds to 10^{-12} s, so we need some 10^{12} such steps, that is $\sim 10^{18}$ spin-updates. One typically wants to collect statistics on several $\sim$ 10x10 copies of the system, adding up to $\sim 10^{20}$ Monte Carlo spin updates. Therefore, performing this simulation program in an acceptable time frame (say, less than 1 year) requires a computer system able to update on average one spin per picosecond or less.

This analysis shows that accurate simulations of SGs have been a major computational challenge; and needs a very huge number of computational resources. Also it's very beneficial to mention that most of available algorithms are based on Monte Carlo Simulations. If we increase the size of each SG chain, the Monte Carlo simulations count is being significantly increased which also in its turn requires a lot of computations. Therefore, the energy consumption must be taken into account. Having a deep vision on this application, the main focus will be is to create a customized and acceptable DVFS policy to have best performance with minimal energy consumption.

III. Experimental Methodology

Classical model of power consumption of a server is often assumed to be quite simple

$$PowerConsumed = P_min(F_i) + (P_{max}(F_i) - P_min(F_i)) * Utilization \quad (4)$$

where F_i is the fixed frequency, $P_min(F_i)$ is the minimum power consumed at idle state at the fixed frequency and $P_max(F_i)$ is the maximum power consumed at peak load at the fixed frequency. Utilization is between 0 and 1. We use the affine model because the aim of the article is not on the power model choice, but that we could use other more precise model [11]. In our study we use affine model that contains one static part (fix cost) and a dynamic part which vary proportionally to the CPU load.

HPC systems are usually getting the maximum available frequency as the goal is to produce a maximum throughput. But waiting for communications at the maximum speed is not necessary. The classical approach is to compute for each task the optimal frequency depending on the ratio communication/computation.

By reducing the frequency we will have some time penalty which is not only due to the lower frequency but also due to the load imbalance created by the different processor speeds. In HPC applications, where there is an interdependence of tasks across processors, if one processor is slowed down, the entire application may consequently be slowed down. Even if there are no such dependencies, there will be load imbalance between the processors. As a result, decreasing the frequency will result in degradation of performance and increase in the total execution time. So it is important to have a well defined policy for changing the frequency using DVFS. In this case, when a particular application needs raw computing power, the frequency will be maximum, but the frequency will be lower for each communication [12], [13].

For conducting the experiment the CloudSim framework has been used [14], which is a framework for modeling and simulation of cloud computing infrastructures and services. It additionally provisions hosts to VMs, application execution management and dynamic system state monitoring. The characteristics of the main components of the CloudSim framework we used are the following:

- In cloud analysis, there are six regions that correspond to six continents in the world. We used the region Asia as Armenia located in that region.
- The Data center encapsulates a set of computing hosts or servers that are either heterogeneous or homogeneous in nature, based on their hardware configurations. The center which has been created is corresponding to the Armcluster resources, the DataCenterArmCluster consist of the following architecture: System architecture is x86, Operation system is Linux, 48 cores, 48Gb RAM, bandwidth 60000Mb and 3000Gb HDD.
- The types of the Hosts, which describe the physical resources (compute or storage) is the following: 8 cores, 8Gb RAM, 10000Mb bandwidth and 20 Gb image size.

The service which adjusts frequency in the operating system is known as a governor. Distinctive governors can be executed with diverse approaches in regard to frequency management, where each mode has a governor to decide whether the frequency must be changed (increased or decreased) or not. The following three DVFS modes have been taken into account:

- Performance: the frequency is always fixed at the highest level, even if the processor is not utilized.
- Ondemand: the frequency is balanced according to the workload behavior.
- Powersave: the frequency is always fixed at the lowest level.

The processors have only three frequency rates: 2.0GHz, 2.33GHz, 2.5GHz. The experiment will be conducted for about ten times with each frequency rate, and the average value will be taken in term of execution time in seconds and energy consumption in watts. The experiment will be run using an XML file as an input which contains the input parameters of the experiment and the three available frequency rates. We have static and dynamic governors enabling to analyze the behavior and impact of the execution. The static governors do not perform any frequency change during the execution but the dynamic ones are able to do this. The main aim of the experiment is to perform a series of simulations based on several DVFS modes in order to study the behavior of DVFS on SG performance. The Tables 1 and 2 show available modes and Powers at 0% and 100% of CPU load for each frequency.

TABLE I
AVAILABLE MODES OF DVFS USING THE MIPS IN CLOUDSIM.

HOST	powersave	ondemand	perf.
%*Fmax	80.0	93.2	100.0
CloudSim(MIPS)	5464	6304	6830

TABLE II
POWERS IN WATT AT 0% AND 100% OF CPU LOAD FOR EACH FREQUENCIES.

Frequency (GHz)	2.0	2.33	2.5
Pmin	140	146	153
Pmax	228	238	249

IV. Results and Discussions

After running the simulation for each DVFS mode for ten times, the average result has been obtained for time execution in second and power consumption in W/h which are represented in the following table:

The figure 2 illustrates the difference between the conservative and ondemand governors.

From the result we can see that the execution time is the same in any DVFS mode, but in OnDemand and PowerSave mode we have an appropriate saving in power consumption.

TABLE III
SIMULATION RESULTS USING THREE DVFS MODE.

DVFS mode	Duration (s)	Energy (W h)
Performance	48.0	17.86
OnDemand	48.0	17.64
PowerSave	48.0	17.64

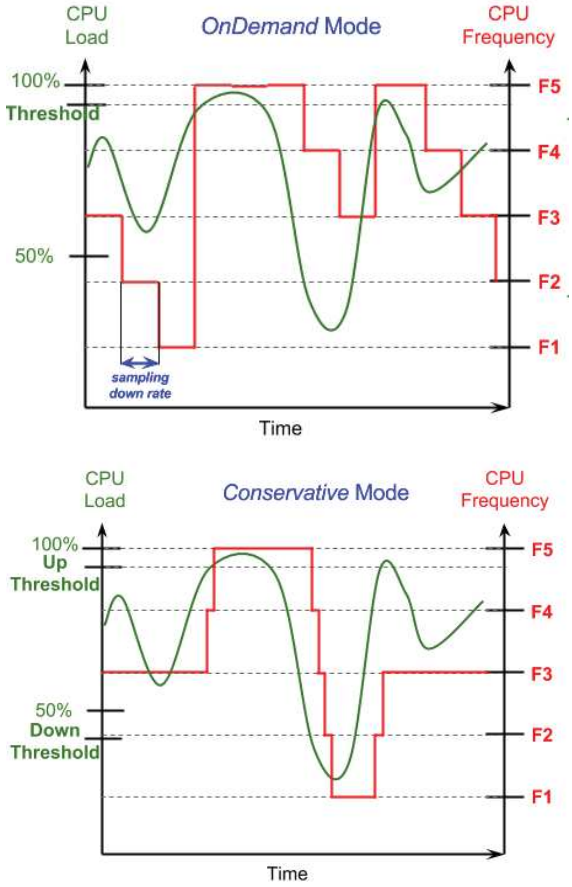

Fig. 2. the difference between the conservative and ondemand governors: the red line represents the Frequency, the green one represents the CPU load.

Depending on the result we can say that this experiment can be run automatically in OnDemand mode because it will give the system the possibility to balance the frequency depending on the operation system and all other processes in the system and the best energy saving will be achieved.

V. CONCLUSION

The purpose of this article was to study the behavior of DVFS method for 3D Classical SG problem. The results and discussions sections give interesting conclusions about DVFS behavior,which was found to be closely linked with the internal architecture of the hosts within the data center. Because the execution time of OnDemand and PowerSave is the same the OnDemand mode is the best DVFS mode for SG experiment due to the power consumption and frequency balance for the system.

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