Application of Virtualization Technology in High-Performance Computing

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Abstract—In software, hardware, data centers and cloud computing, the figures of virtualization technology can be seen. Where the virtualization technology has not really been involved in is in high-performance computing. By analyzing the specific applications of virtualization technology and the possible challenges it will face if applied in high-performance computing, this paper highlights the virtualization technology application prospects in high performance computing.

Index Terms—virtualization technology, high-performance computing, Application prospects

I. INTRODUCTION

Compared with the extensive application in x86 server field, virtualization technology’s application in high performance computing is relatively scarce [1]. As we all know, the extensive use of virtualization technology in x86 servers has a necessary condition - the utilization and load of the server’s CPU is low. In high-performance computing, the main focus is on the implementation of parallel high-density high-load task, and the processor is almost close to full capacity all the time. At the same time, high performance computing workloads is more influenced by memory bandwidth, I/O bandwidth. It seems that virtualization and high performance computing can be described as "incompatible". This view about the application of high performance computing virtualization technology is also universal among the majority [2].

As all PC servers are not suitable to be virtualized, it is not true that in high performance computing all applications are not suitable to be virtualized. To some extent, virtualization is just the effective way to enhance the extra value of high performance computing, and even the best choice to solve the traditional difficulties high performance computing has been faced with.

II. VIRTUALIZATION TECHNOLOGY AND HIGH PERFORMANCE COMPUTING

Virtualization technology first appeared in IBM mainframe systems in the 60s and 70s of the last century to support high-level software sharing underlying hardware resources, to provide users with multiple applications running environment. At present, the virtual infrastructure can improve x86 server utilization from 5%-15% to 60%-80%, and in tens of seconds to complete the resources allocation of new applied system [3]. Virtualization technology has been functioning well in PC and application server, which has produced a series of successful virtualized software like VMware, Virtual PC and Xen. The hardware manufacturers is joining the ranks of virtualization, prompting the advancement of virtualization technology. The hardware includes VT-X in Intel, VT-i and VT-d technology, Pacific in AMD and so on.

HPC (short for High-Performance Computing) is a branch of computer science, focusing on parallel computing and developing software, being committed to developing high performance computers [4]. With the rapid development of information society, HPC has become the third pillar of scientific research, following after the theoretical science and experimental science. In some emerging disciplines, such as new materials technology and biotechnology, high performance computers have become an indispensable tool for scientific research. With further research and increased competition, HPC is adopted to solve scientific and practical problems in production more and more. The development of HPC application not only prompts the innovation of science and technology, but the progress of society. The level of HPC’s application is becoming a key indicator in measuring a nation’s comprehensive national strength and international competitiveness.

III. THE POSSIBLE APPLICATION OF VIRTUALIZATION TECHNOLOGY IN HPC

With the development of HPC and further study of virtualization technology, the combination of these two is bound to become closer and closer. It is possible for virtualization technology to provide the difficulties in HPC with new methods [5]. Viewing from the respect of application, the combination of these two may appear in the following several forms:

A. Improve development efficiency.

HPC applications are closely related to computing environments and the behavior under the operation scale of different circumstances appears different. With
virtualization technology, large-scale virtual application development environment can be built on small-scale systems, so that application programs can be developed and optimized under the environment which is much closer to the final system environment, and application programs can be transported to run in large-scale systems more quickly and easily.

B. Integrating heterogeneous resources

With the development of the application requirements and HPC, high performance computer systems are gradually developing towards the heterogeneity. How to manage and use heterogeneous systems efficiently is the major technical problem that HPC system software and application program developers face. Virtualization technology holds inherent advantages in integrating heterogeneous resources. Making use of virtualization technology to abstract and manage the underlying heterogeneous hardware resources can effectively hide the heterogeneous characteristics of the hardware platform and provide users with a unified system environment, making it convenient to use heterogeneous systems.

C. Providing customized Appliance

Different HPC application programs require different system environments, such as application-optimized operating system environment, a specific version of the compiler and the communication library, etc., which takes too much time and effort in application deployment; the system environment is also difficult to optimize, and system performance are not full. The adoption of virtualization technology contributes to the resolution of the problems mentioned above. Virtualization supports packaging customized operating system in advance and optimized application running environment with the binary code into the VM (short for Virtual Machine) image, which is known as appliance. Through the direct deployment of Appliance, the fast deployment of HPC application programs can be realized and better performance can be reached.

D. Improving reliability and fault tolerance of the system

With the constant expansion of HPC, the continuous complexity among different parts, the failure rate of the system hardware is also growing. Checkpoint is often used to solve this sort of problems, keeping the intermediate results and then restarting the system. Checkpoint is traditionally made in the way of programming the code by users themselves. Because it would involve a number of border issues, there is higher requirement and a big challenge for users. By adopting virtualization technology, the state of a virtual machine can be well preserved, providing us with a clean border. Besides, in the virtualization system, due to isolation of each VM in the Q nodes, software errors, such as operating system or application failure only directly affects one VM, or even hardware failure, such as CPU, Memory, and equipment failures only affect the VMs they are assigned to. When a failure appears, it can be restored quickly through VM migration, restarting the VM and other methods, even without interrupting running applications.

E. Improving the security of HPC systems

System security is very important to HPC applications like the data center, and the isolation among VMs and self-testing capability provides a platform for establishing security system. As VMM (short for Virtual Machine Manager) only provides the abstraction and management of underlying hardware with some simple functions, it is more reliable and secure as opposed to a full-featured operating system kernel. VMM is not subject to interference from malicious code; the isolation between the VMM and authorized self-test feature are fully credible. VMM can check the credit of the loaded VM and the application programs loaded onto the VM, and it can authorize a VM to examine the VM state, such as scanning for viruses. Besides, VMM can also monitor the communication and state between VMs to ensure its correct running.

Only from the perspective of applications, the combination of virtualization technology and HPC may appear these several form of possibilities. In fact, high-performance computing hardware itself, especially the rapid improvement of processor performance, makes it more probable for virtualization technology to enter the HPC, functioning as a "good wife". In the past, CPU utilization of HPC is almost 100%, but with the latest Intel and AMD processors launched, the performance of HPC has been improved unprecedentedly. As the number of single-core CPU increases, even if in a single computing node, the application will not necessarily occupy all the Core (core). Thus, the remaining core can meet some program application whose requirements of the I/O and bandwidth are not particularly high. While how these applications can be put onto the core at idle and isolated correspondingly, how to ensure these operations do not conflict with the original, for which virtualization technology can provide a better solution. With the rapid development of Intel's VT technology, it is turned into reality to improve the IT structure and enhance the value of IT to become by adopting virtualization technology.

IV. THE CHALLENGES TO FACE AND THE STUDIES TO CARRY OUT

Although, virtualization technology may bring great possibility to increase the value of HPC, by farther adoption of virtualization technology in HPC is scarce, which is mainly due to the following several aspects:

F. Performance overheads brought by virtualization

Traditional server virtualization brings extra performance overheads. In a virtualization system, VMM run at the highest privilege level, and VM and Guest OS run as the user-level VMM. This leads to the fact that in running, Guest OS must be embedded into VMM when faced with the privilege operation. This approach requires for the implementation of context switching, and would result in longer delay in accessing devices, which are
unacceptable for HPC applications that are sensitive to the system performance. Hence, the virtualization technology which is just intended for HPC system needs developing and it is necessary to optimize VMM technology based on the requirements of HPC.

G. The efficient coordination of many VMMs

The virtualization technology intended for HPC system is different from the traditional server virtualization technology. In traditional server virtualization, only one single VMM is needed to abstract the underlying hardware. While in the multi-dimensional heterogeneous HPC system, one separate VMM is needed in every node and this VMM only virtualizes that single node. In the whole system, a large number of interrelated VMMs run, and they also work in coordination, forming a unified virtualization environment of large-scale system level. Therefore, it is necessary to study efficient VMM coordination mechanism, including the technological problems like the coordination management of a large number of VMMs, coordination deployment, the efficient communication of VMs across physical nodes, VM migration, and so on.

H. The management of a large number of VM

In order to support the operation of HPC program, it may be necessary to deploy thousands of VMs at one time. While, traditional server virtualization technology can tackle the deployment and management of a small number of VMs. Thus, how to support the dynamic deployment of a large number of VMs, how to allocate the necessary hardware resources fast according to application requirements, how to start VM quickly with lower system overhead, how to manage a large number of VMs in operation, all of which are the important technical issues to achieve HPC virtualization.

I. Programming model and the support of software environment

The traditional programming model and the software environment supporting application development and operation are all directly intended for non-virtualization system; while, virtualization technology abstracts hardware system, changes the organization morphology of resources users see, so that the traditional programming model and software environment is in no way able to meet users’ requirements about virtualization system. Hence, it is necessary to develop new programming model directed at virtualized HPC system and the corresponding optimized software environment intended for virtualized system, such as parallel compiler, linker, debugger optimization tools, parallel libraries, etc.

In a word, the application of HPC usually requires high performance; while on the other hand, virtualization will definitely lead to the damage of performance, which is almost unacceptable to most of HPC application. Therefore, it is necessary to develop efficient virtualization technology particularly intended for HPC system, such as the virtual model for high-performance computer systems, application development and deployment mechanism on large-scale virtualized systems, programming model and corresponding software environment supporting virtualization system [7]. With the continuous development of virtualization technology, the underlying hardware provide virtualization with increasing support, lowering the performance overhead of virtualization [8]. The trend of the high-performance computer architecture developing towards a multi-level, multi-granularity isomerization will further promote the development of virtualization technology.

V. CONCLUSION

To some extent, what hasn’t been turned into reality is of certain possibility. Though analyzing the application prospect of virtualization technology in HPC, the chances and challenges virtualization may face in HPC are emerging easily. It is believed that HPC in the future will set a stage for virtualization. By discussing these chances and challenges as well as constant examination of the practice, both virtualization and HPC can be improved greatly. Meanwhile, the value of IT will increase gradually with the improvement of technology.

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