Performance Evaluation of Virtualization Tools in Multi-Threaded Applications

Review

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Abstract *– In the last decade, virtualization technologies have become very popular. Virtualization enables a user to run multiple operating systems on the same computer concurrently, while providing a degree of isolation between OS instances. Even though virtualization is mostly used on servers, its popularity on desktop also rises, where it is mostly used in cross-platform development and execution of software available to other platforms. Since both of these use cases are performance intensive, the goal of this paper is to evaluate the performance of a couple of the most popular desktop virtualization tools on the market, i.e., VMWare Player and Oracle VirtualBox. Benchmarks used in this paper evaluate the performance of the tools in both CPU intensive and GPU intensive applications, with special emphasis placed on the performance of multi-threaded applications.*

Keywords *– multi-threading, performance evaluation, virtualization, virtualization tools.*

1. INTRODUCTION

Virtualization technologies have achieved enormous popularity in both research community and industry, providing both increased research opportunities and significant savings in operating costs of computing equipment. Reasons for their popularity are numerous, ranging from easier management of simple isolated systems like workstations [1] to improved utilization of computing resources in big complicated systems like those operated by cloud service providers [2].

Virtualization enables simulation of another machine (called a guest machine or a virtual machine) on the hardware of the physical machine where virtualization takes place (called a host machine). It is important to note that while virtualization can be performed entirely in software, in modern systems it is mostly employed in form of hardware-assisted virtualization [3], where both hardware and software work together to improve the performance of virtual machines. Software with the ability to create and run virtual machines is called a Hypervisor or a Virtual Machine Manager [3]. Virtualization software attains such ability by abstracting access to the hardware of the physical, host machine, and presenting it to the virtual machine as distinct hardware configuration specific to that virtual machine. Since a virtual machine behaves like a real computer, it can have its own operating system (called a guest OS), with its own set of software installed. Not only it is possible to run some flavor of the Linux operating system in a virtual machine running on the Windows operating system, but it is also possible to run it completely unmodified [3]. This enables great portability of already preconfigured computing environments between machines with vastly different hardware configurations [4].

Because of its adaptability to almost all use cases, virtualization technologies are present in almost all aspects of computing industry. Some more notable examples of industries and use cases relying heavily on virtualization are cloud service providers, web hosting companies, distributed computing, education sector, hardware and software development companies, and even private individuals.

The ubiquity of virtualization and its use in vastly different industries resulted in a lot of research papers either trying to improve the performance of the technology, or finding new applications for the technology. Some new interesting uses are in education, where virtualization is used as a tool in enabling many different courses to use existing computer classrooms, even though they require different software configurations often not compatible with each other [4]–[6]. Another interesting use is to utilize virtualization to enable easy joining of computers to distributed computing networks so that spare computational capacity of those computers is used to perform useful work [7].

However, it is important to state that virtualization technologies have a lot of drawbacks. A downside of virtualization is mainly increased overhead in utilization of the host computer's hardware [3].

Desktop virtualization is mostly used by individuals for running different guest operating systems on the host operating system. Reasons for doing so are often unavailability of some software package on the desired platform, like running Adobe Photoshop on Linux or Windows games on Mac. Those software packages are often so resource intensive that they tax the machines even without the performance drop due to virtualization overhead.

This paper attempts to quantify that overhead and loss in performance in two mostly used software packages for desktop virtualization. The main contribution of this paper is performance evaluation of VirtualBox and VMWare Player virtualization tools in CPU and GPU intensive applications, such as computer games or 3D modelling tools.

In Chapter 2, the authors show related work in this field, with the focus on performance analysis of different virtualization tools. Chapter 3 gives a short overview of virtualization tools used. Chapter 4 explains the testing methodology in detail, along with hardware configurations used in tests. Results of performed tests are stated in Chapter 5, while Chapter 6 discusses the results.

2. RELATED WORK

Many research papers have been published which focus on the performance aspect of virtualization tools in many different applications, although the area of cloud services and server virtualization performance is getting most of the attention, where some notable examples are [2], [8]–[10]. Some authors show the performance of VirtualBox in cloud environments [11], but compare it to KVM and Xen instead of VMWare Player.

Papers that deal with performance analysis and comparison of similar desktop virtualization tools as used in this paper (namely Oracle's VirtualBox and any of VMWare's desktop virtualization tools) often focus on using benchmarks which evaluated mostly CPU performance and memory throughput. Prakesh et al. [12] evaluated the performance of VirtualBox and VMWare Workstation, but their paper was based on CPU performance and it used only one test with GPU testing capabilities. Other examples are studies [13], [14], which attempted to evaluate performance of VirtualBox, Virtual PC 2007 and VMWare Player under the load similar to the database application using the Postmark benchmark application. Another interesting example is [15], where authors used the LINPACK benchmark for performance evaluation of VirtualBox and VMWare Player. None of these examples evaluate graphically intensive applications.

The authors of this paper found no study which extensively evaluates relative performance between VirtualBox and VMWare Player in applications which were both CPU and GPU intensive, as computer games or 3D modelling tools would be. This paper attempts to show the readers what kind of performance drop they could expect in such applications. It is important to note that this work is the authors' first paper in the field of virtualization.

3. VIRTUALIZATION TOOLS

Currently there are a lot of virtualization tools available on the market with different characteristics and targeting different market segments. In the server virtualization segment, very popular tools are Xen, KVM, VMWare vSphere, Oracle Virtualbox and Microsoft Hyper-V. In the segment of Desktop virtualization, Xen and KVM are not very popular because they are Linux based, while VMWare's vSphere is mostly replaced by VMWare Player or VMWare Workstation. The most commonly used tools in this segment are Oracle VirtualBox and VMWare player because they are both free for personal use.

Oracle VirtualBox is a software package for virtualization of x86 and AMD64/Intel64 computers. It is open source and free and easy to use [16]. It supports a wide range of operating systems (Windows XP/Vista/7/8, Linux, Mac OSX, Solaris, Open Solaris). VirtualBox emulates virtual hardware compatible with the aforementioned operating systems by default. Still, it is possible to improve performance by installing VirtualBox Guest Additions inside the guest OS. Guest Additions contain improved drivers for virtualized hardware and are available for all mentioned operating systems. In addition to improved drivers, Guest Additions enable a lot of features, including shared clipboard, *drag and drop*, automatic screen resize, etc. VirtualBox also supports several disk image standards, including VDI, VMDK, VHD, QED and qcow.

VMWare Player is a virtualization tool created by VMWare. It supports Windows and Linux operating systems, while for Mac OS there is a separate product called VMWare Fusion. VMWare Player is free for personal use, while for commercial use there is VMWare Player Plus [17]. Similarly to VirtualBox, VMWare Player hardware is also supported by default in both supported operating systems, but for improved performance it is advisable to install VMWare Tools. VMWare Tools also enable both special drivers for virtualized hardware and additional features similar to those of VirtualBox Guest Additions. Some notable features of VMWare Player not present in Virtualbox are: Unity, USB 3.0 support, hardware accelerated virtualization and Easy Install (unattended OS installation) [18].

4. TESTING METHODOLOGY

This paper attempts both to evaluate performance of stated virtualization tools compared to the performance of the native environment and to evaluate performance of the tools themselves. Performance is evaluated by using several benchmarking tools, on two distinct hardware configurations running 64 bit Windows 7 Ultimate as a host operating system and 32 bit Windows 7 Ultimate as a guest operating system. Hardware configurations of test computers are shown in Table 1. 32-bit versions of the guest OS were used because the lower end configuration (PC1 in Table 1) had problems with running a 64-bit version of the guest OS in VirtualBox. The authors assume that the problems with the 64-bit guest occurred because of bugs in CPU's virtualization support, where VirtualBox could not detect proper virtualization extensions in CPU. It is evident from [19], [20], that other AMD users had the same problem with similar AMD CPUs and for that reason 32-bit versions of the guest OS were chosen.

Table 1. Test PCs hardware configurations

	PC1	PC2
CPU	AMD Athlon 64 X2 6000+ 3.1GHz	AMD Phenom II X6 1055T 2,8GHz
GPU	NVIDIA GeForce 9600GT 512MB GDDR3	AMD Radeon HD6850 Toxic 1GB GDDR5
RAM	4GB DDR2 800MHz	8GB DDR3 1600MHz
HDD	Seagate 500GB 7200RPM 16MB Cache	Hitachi 1.5TB 7200RPM 64MB Cache

Table 2. Test PCs VM configuration parameters

	PC1	PC2
Allocated number of CPU cores	2	6
Allocated GPU memory	128MB	128MB
Allocated RAM memory	2GB	4GB
Allocated HDD space	Fixed size 40GB	Fixed size 40GB

Native environment tests were performed on a clean Windows install, with only benchmarking tools installed. After that, VirtualBox was installed and the guest OS was set up with the same benchmarking tools, after which the tests were performed. After that, VMWare Player was installed, its guest OS was set up and its tests performed.

Configuration parameters of guest VMs are shown in Table 2. Both virtualization tools were configured to emulate the same number of CPU cores as their host computer processor had. Allocated GPU memory in both virtualization tools was set to the maximum value available in VirtualBox, which is 128MB. Even though VMWare Player can allocate more GPU memory to guest VM than VirtualBox, the amount of GPU memory was set to the same value in all configurations to keep settings consistent among tools. Both host computers had the latest (at the time of performing the tests) official GPU drivers installed, i.e., *nVidia Geforce v340.52 driver* and *AMD Catalyst Software Suite v14.4* for PC1 and PC2, respectively. Guest operating systems on both virtualization platforms had their respective latest version of *guest addon* software installed, i.e., the *VirtualBox Guest Additions* for VirtualBox and *VMWare Tools* for VMWare Player. The amount of RAM memory available to the guest OS was set to half of computer physical memory to ensure that the host OS will have enough memory for background tasks and will not interfere with the results. Virtual hard disks on both platforms were configured as a 40GB fixed size disk file.

Benchmarking tools used in testing are: PCMark 5, 3DMark 03, NovaBench, Performance Test and wPrime. PCMark 5 and 3DMark 03 are very popular benchmarking suites developed by FutureMark. PCMark 5 consists of 11 system tests, 8 processor tests, 16 memory tests, 8 graphics performance tests and 5 disk performance tests. It is mainly used for whole system testing, and its reported score can depict the performance of the whole system. 3DMark 03 is mostly used for graphics performance testing and all its tests try to show how the tested system would behave in computer games. Its testing sequence consists of 4 game tests, 2 processor tests, 5 feature tests and 3 sound tests. NovaBench and Performance Test are benchmarking suites also commonly used in performance testing. The last tool used in testing was a tool called wPrime, also a popular benchmarking tool, which is a program that tests the CPU performance by calculating square roots with a recursive call of Newton's method for estimating functions [21]. This tool tests mainly the CPU and it supports multithreading, so it can test all cores of the processor simultaneously.

Even though most of the benchmarking tools used in this paper test all hardware components of the computer system, this paper shows only the results pertaining to CPU and GPU performance.

5. RESULTS

Test results are grouped by benchmarking tools and shown in Tables 3 - 7. The first column in these tables shows the test that is run and the configuration it is run on. The second column shows numeric results attained in the native environment in that test. The third and the fourth column show numeric results of the test in VirtualBox and the percentage drop in performance of that test in VirtualBox compared to the same test in the native environment, respectively. The fifth and the sixth column show numeric results of the test in VMWare Player and the percentage drop in performance of that test in VMWare Player compared to the same test in the native environment, respectively.

Table 3 shows results of the PCMark 5 benchmarking suite while following the above described format. The results show that the native environment has a significant performance advantage compared to both virtualization environments, which was to be expected. Table 3 also shows that of the two virtualization environments compared, VMWare Player is shown to be a clear winner. The performance drop in VMWare player was less than that of VirtualBox in all tests conducted, especially on high-end configuration (PC2). VirtualBox could not even run all the tests on high-end configuration (PC2). It is evident from the results in Table 3 that while CPU performance drop is relatively acceptable for the advantages it brings, GPU performance drop is big enough (87.89% in the best case) to make GPU intensive applications unusable in the virtualized environment.

Table 4 shows results of the 3DMark 03 benchmarking suite. Since the 3DMark suite tries to evaluate what kind of performance the machine could have in computer games, the results show that VMWare is a clear winner in this segment, too. The performance drop of VMWare Player is consistent in both configurations, with 24.38% and 24.9% in the first and the second PC configuration, respectively. VirtualBox obtained significantly lower scores, with the performance drop of 78.66% and 74.3% in the first and the second PC configuration, respectively. According to these results, VMWare Player could be used for gaming in the virtualized environment despite a significant performance loss, while VirtualBox can be used only for playing very old and undemanding computer games.

It is also notable that CPU scores obtained in these tests were not consistent with CPU scores obtained in PCMark tests, with a performance drop ranging from 64% to 92%. The authors speculate that the reason for this inconsistency is a relatively low number of CPU tests performed in 3DMark compared to PCMark (2 CPU tests compared to 8 CPU tests, respectively), and the fact that 3DMark stress tests all hardware components simultaneously, while PCMark tests are more targeted towards individual components.

Table 5 shows the results in the NOVABENCH benchmarking suite. This experiment also shows that VirtualBox has a significantly larger performance drop compared to VMWare Player, but in this experiment CPU performance of both environments was similar. The difference in the overall performance in this experiment resulted from a big difference in the results of GPU tests between VMWare Player and VirtualBox, where VMWare Player had performance drops of 45% and 32% on PC1 and PC2, respectively; while VirtualBox had significantly larger performance drops of 97% and 91% on PC1 and PC2, respectively. This result confirms the results shown in Table 3 (PCMark suite), which also showed a significantly larger performance drop of VirtualBox compared to VMWare Player in GPU intensive applications.

Table 6 shows the results of the Performance Test benchmarking suite. The Performance Test is a very detailed test that evaluates all hardware components. In this suite, *Complete Score* of both virtualization tools was similar, especially on PC2. The reason for that was the fact that VirtualBox has a lot better IO performance scores than VMWare Player, which improves VirtualBox score even though it scored significantly lower in 3D graphics tests than VMWare Player in both PCs. It should be noted that IO performance testing is beyond the scope of this paper. CPU scores are similar in both tools, while 2D graphics score is the only test in this paper where VirtualBox had better results than VMWare Player.

Finally, Table 7 shows the results of the last experiment in this paper, conducted using the wPrime benchmark. wPrime benchmarks run on 4 threads simultaneously and they exclusively test CPU performance. Previous tests also run on multiple threads, but unlike this test, they did not max out all cores all the time. The results show that on PC1 both tools were performing similarly, while on PC2 VMWare Player again had a slight advantage.

Table 3. Experiment results of PCMark5

PCMark5	Native environment	VirtualBox	%	VMware Player	%
PC1 CPU Score	6186	4274	30.91	4989	19.35
GPU Score	12214	668	94.53	942	92.29
PC2 CPU Score	10118	5171	48.89	7200	28.84
GPU Score	18310	-	-	2217	87.89

Table 4. Experiment results of 3DMark3

3Dmark3	Native environment	VirtualBox	%	VMware Player	%
PC1 Game Score	31858	6799	78.66	24092	24.38
CPU Score	1710	122	92.87	609	64.39
PC2 Game Score	64018	16451	74.3	48079	24.9
CPU Score	2129	160	92.48	854	59.89

Table 5. Experiment results of NOVABENCH3

NOVA BENCH3	Native environment	VirtualBox	%	VMware Player	%
PC1 Complete Score	622	246	60.45	377	39.39
CPU Score	240	152	36.67	153	36.25
GPU Score	252	7	97.22	137	45.63
PC2 Complete Score	1191	276	76.83	565	52.56
CPU Score	560	156	72.14	173	69.11
GPU Score	443	27	91.91	300	32.28

Table 6. Experiment results of Performance Test

Performance test	Native environment	VirtualBox	%	VMware Player	%
PC1 Complete Score	1169.1	473.2	59.52	654.4	44.03
CPU Score	1938	785.3	59.48	811.9	58.11
2D Graphic Score	437.8	420.5	3.95	366.5	16.29
3D Graphic Score	1023.6	82.2	91.97	429	58.09
PC2 Complete Score	1795.8	798.7	55.52	799.3	55.49
CPU Score	5831.5	850.1	85.42	990.4	83.01
2D Graphic Score	373.8	1015.4	0	480.7	0
3D Graphic Score	2594.5	435.1	83.23	839.4	67.65

Table 7. Experiment results of wPrime

wPrime	Native environment	VirtualBox	%	VMware Player	%
PC1	947.562	2045.88	53.68	1995.36	52.51
Thread 1 [sec]	929.919	2041.14	54.44	1989.51	53.26
Thread 2 [sec]	921.541	2043.44	54.90	1989.00	53.67
Thread 3 [sec]	947.562	2045.87	53.68	1995.36	52.51
Thread 4 [sec]	928.967	2041.81	54.50	1994,37	53.42
PC2	288.396	1812.93	84.09	1593.98	81.91
Thread 1 [sec]	287.211	1806.52	84.10	1593.96	81.98
Thread 2 [sec]	286.259	1809.08	84.18	1583.70	81.92
Thread 3 [sec]	288.396	1812.45	84.09	1593.96	81.91
Thread 4 [sec]	287.663	1812.93	84.13	1585.46	81.86

6. CONCLUSION

The results of conducted experiments have shown that VMWare Player had better performance in almost all tests than VirtualBox, with the difference in CPU performance being a lot smaller than the difference in GPU performance, but still significant. It is also visible from the results that virtualization tools have a smaller performance drop in single threading applications than in multithreading applications, with the multithreading performance drop ranging up to 90%.

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